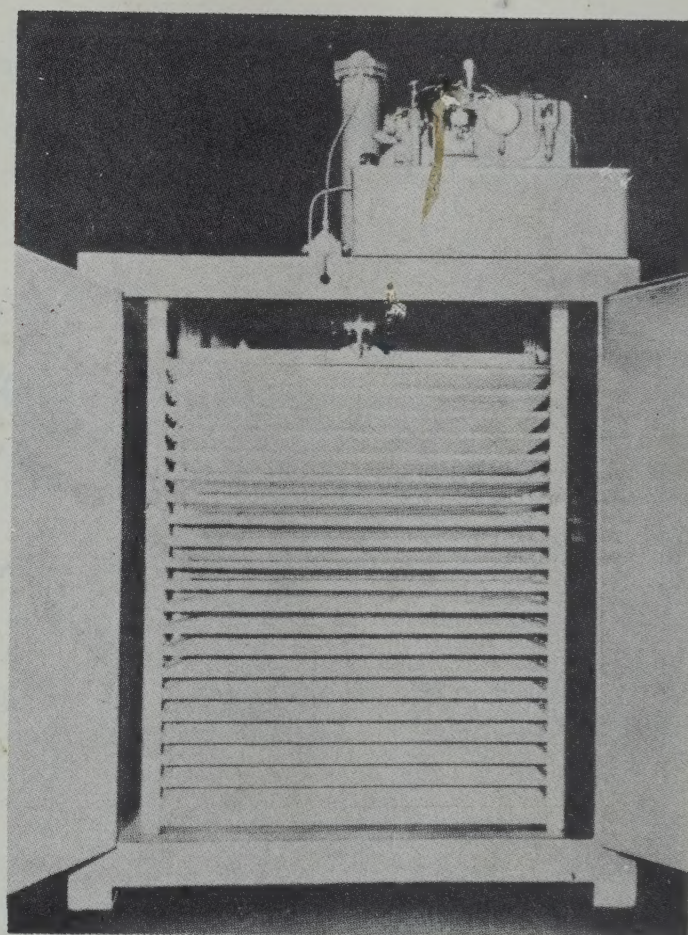
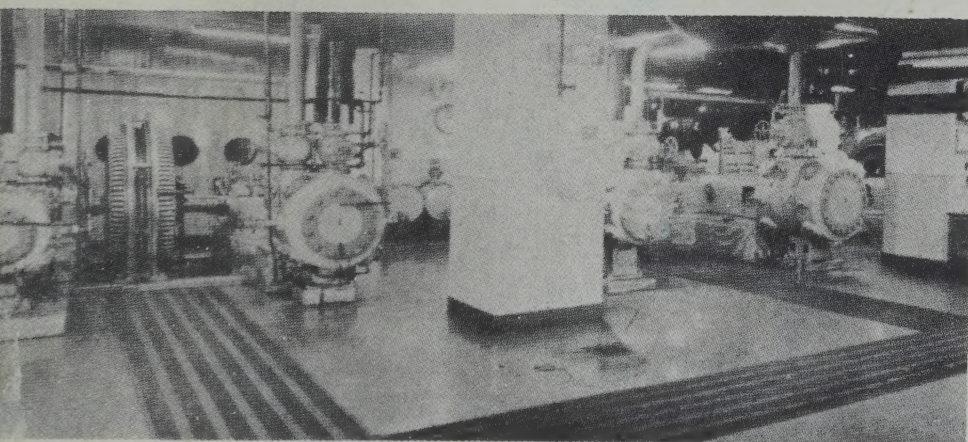
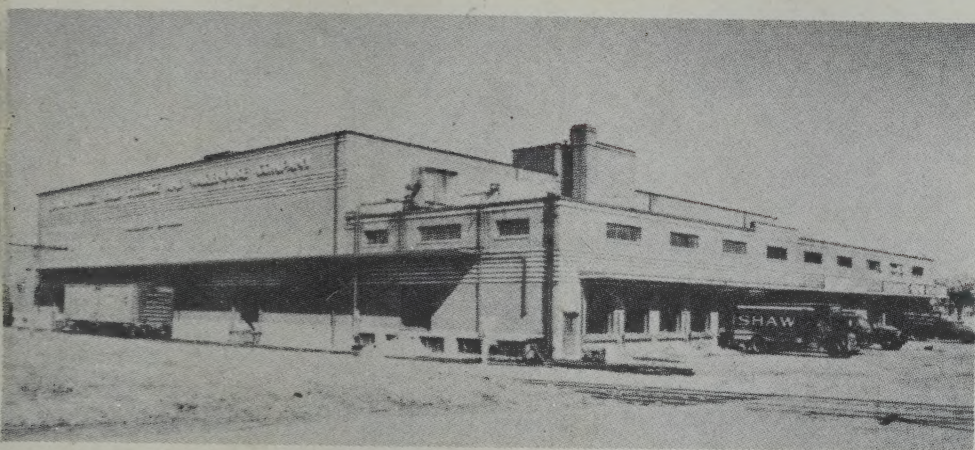


82-148-149

FISH TECHNOLOGY EXPERIMENT STATION.
Mangalore Bazaar, MANGALORE-L.

COLD STORAGE DESIGN AND REFRIGERATION EQUIPMENT

REFRIGERATION OF FISH - PART 1



UNITED STATES DEPARTMENT OF THE INTERIOR

Fred A. Seaton, Secretary

FISH AND WILDLIFE SERVICE

John L. Farley, Director

Fishery Leaflet 427

C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION.
Molase Bazaar, MANGALORE-1.

Lib. no. 67/2.8.67.
2

Fishery Leaflet 427

Washington 25, D. C.

June 1956

REFRIGERATION OF FISH - PART ONE

COLD STORAGE DESIGN AND REFRIGERATION EQUIPMENT

By Charles Butler (Section 1), Joseph W. Slavin (Sections 1, 2, and 3),
Max Patashnik (Section 1), and F. Bruce Sanford (Section 1)

Table of Contents

	<u>Pages</u>
Section 1 - Cold Storage Design	1 - 74
Section 2 - Refrigeration Equipment	75 - 110
Section 3 - Refrigeration Requirements and Freezing Methods . .	111 - 146

[A detailed table of contents is at the beginning of each section]

This leaflet is part one of a series of five to be prepared within the broader overall subject matter of the refrigeration of fish. Titles of the other four leaflets are:

- *Fishery Leaflet 428 - Handling Fresh Fish
- Fishery Leaflet 429 - Factors to be Considered in the Freezing and Cold Storage of Fishery Products
- Fishery Leaflet 430 - Preparing, Freezing, and Cold Storage of Fish, Shellfish, and Precooked Fishery Products
- *Fishery Leaflet 431 - Distribution and Marketing of Frozen Fishery Products

The five leaflets in this series are prepared under the general supervision of Charles Butler, Chief, Technological Section, Branch of Commercial Fisheries, Washington, D. C., and edited by Joseph W. Slavin, Refrigeration Engineer, Fishery Technological Laboratory, East Boston, Massachusetts, and F. Bruce Sanford, Chemist, Fishery Technological Laboratory, Seattle, Washington.

* These leaflets have not yet been published.

C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION.
Horse Bazaar, MANGALORE-1.

SECTION 1

COLD STORAGE DESIGN

By Charles Butler, Chief, Technological Section; Joseph W. Slavin, Refrigeration Engineer; Max Patashnik, Fishery Products Technologist; and F. Bruce Sanford, Chemist *

TABLE OF CONTENTS

	Page
Introduction	6
Location	6
Design and construction	7
General design features	8
Multistory warehouse	9
One-story and modified one-story warehouse	12
One-story warehouse	12
Modified one-story warehouse	14
Walk-in freezers and coolers	18
Specific design features	19
Refrigerated surfaces	19
Bare pipe coils	19
Finned pipe coils	20
Refrigerated plates	21
Blower-type unit coolers	21
Insulation	22
Function and properties of insulation	22
Selection of insulation	22
Application of insulation	23
Freezer floors	23
Refrigerator doors	25
Product environment	27
Temperature	27
Relative humidity	28
Sample problem	29
Adding moisture to the room	30
Increasing surface area of the coil	30
Jacketed principle	30
Air circulation	31
Calculation of the cold-storage requirements of fish	32

* Branch of Commercial Fisheries, Washington, D. C.; Fishery Technological Laboratory, East Boston 28, Massachusetts; Fishery Technological Laboratory, Seattle 2, Washington; Fishery Technological Laboratory, Seattle 2, Washington, respectively.

How to calculate the heat-gain load in the cold-storage room	32
Relationships between symbols representing quantity of heat and rate of heat flow	32
Symbols employed	32
Example of typical use	33
Wall-heat-gain load	33
Basic heat-flow equation	33
Conductivity constant (k)	34
Calculation for single-wall construction	36
Calculation by use of basic heat-flow equation	36
Calculation by use of table	36
Calculation for multiple-wall construction	38
Calculation neglecting air films	39
Calculation including air films	40
Thickness of insulation	41
Outside design temperature	42
Determination of outside design temperature	43
Corrections to outside design temperature	43
Air change or service load	43
Service load estimated on basis of wall-heat-gain load	44
Service load estimated on basis of volume of refrigerator	44
Product load	46
Formulae for calculation	46
Quantity of heat removed (Q)	46
Product load (q_p)	47
Sample calculation	47
Specific heats and latent heat of fusion	48
Rate of cooling or of freezing	49
Miscellaneous load	50
Electric motors	50
Heat-load equivalent	50
Sample calculation	51
Electric lights	51
Heat-load equivalent	51
Sample calculation	51
Occupancy by people	51
Heat-load equivalent	51
Sample calculation	52
Total miscellaneous load	53
Total heat load	53
Method of calculation	53
Rule-of-thumb methods	53
How to calculate the size of the compressor	54
Method of rating compressors	54

	Page
Method of determining required size of compressor	55
Calculated total heat load (q^t)	55
Hours of operation of compressor (t_c)	55
No defrost cycle	55
Natural defrost cycle	55
Artificial defrost cycle	56
Calculated capacity of compressor (q_c or q_{ct})	56
Evaporative temperature	57
Selection of compressor size	57
How to calculate the size of the evaporator	58
Formula for calculation	58
Bare pipe coils or tubing	59
Overall-heat-transfer-coefficient values	59
Determination of required coil area	59
Finned pipe coils	60
Overall-heat-transfer-coefficient values	61
Refrigerated plates	63
Overall-heat-transfer-coefficient values	63
Determination of required plate area	63
Blower-type unit coolers	64
Method of rating	64
Selection of suitable unit cooler	64
Overall illustrative problem	66
The problem	66
Information required	66
Determination of thickness of insulation	66
Determination of size of room	67
Length of room	67
Width of room	67
Height of room	67
Volume of room	68
Determination of area of insulation	68
Determination of size of compressor	68
Calculated total heat-gain load (q^t)	68
Wall-heat-gain load (q_w^t)	69
Product-heat-gain load (q_p^t)	69
Service-heat-gain load (q_s^t)	69
Miscellaneous-heat-gain load	69
Calculated value of q^t	70
Hours of operation of compressor (t_c)	70
Calculated capacity of compressor (q_c)	70
Evaporative temperature	70
Selected size of compressor (q^*)	70
Determination of the size and quantity of refrigerated plates	71
Bibliography	72

ILLUSTRATIONS

	Page
Figure 1.—A multistory warehouse	9
Figure 2.—Storage of mackerel in a multistory warehouse. .	10
Figure 3.—Handling frozen products in a converted palletized multistory warehouse	11
Figure 4.—A fork lift truck handling frozen products in a refrigerated warehouse	12
Figure 5.—Unloading frozen products from a refrigerated truck	14
Figure 6.—A modified one-story warehouse	14
Figure 7.—Product storage on the mezzanine floor of a refrigerated warehouse	15
Figure 8.—Unloading frozen products from a refrigerated railroad car	16
Figure 9.—View showing the first floor and mezzanine floor in a public warehouse	16
Figure 10.—Product storage on the first floor of a modified one-story warehouse	17
Figure 11.—Cracking and bulging of a freezer floor	24
Figure 12.—An infitting freezer door equipped with a set of flapper doors to minimize loss of cold air while the storage room is being loaded and unloaded	25
Figure 13.—An overlap freezer door with heater cables embedded beneath the cover plate on all three sides of the door frame	26
Figure 14.—Standard conditions for determination of conductivity constant	34
Figure 15.—Cross section of wall of cold-storage room . .	39

TABLES

Table 1.—Thermal conductivities of some common insulating materials	35
---	----

	Page
Table 2.--Wall-heat gain for various temperature differences and thicknesses of cork or equivalent insulation (based on thermal conductivity, $k = 0.30$)	37
Table 3.--Recommended minimum thicknesses of insulation for refrigerators located in the northern or southern part of the United States, based on standards of the refrigeration industry	42
Table 4.--Correction to outside design temperature for solar radiation	43
Table 5.--Data for estimation of air change or service load: average air changes per 24 hours due to door openings and air infiltration for cold-storage rooms of various volumes	44
Table 6.--Data for estimation of air change or service load: heat given up by outside air in cooling to cold-storage temperatures	45
Table 7.--Heat equivalent of electric motors under various conditions	50
Table 8.--Heat equivalent per person working in cold-storage room	52
Table 9.--Calculation of total heat load	53
Table 10.--Outside surface areas of copper tubing and of steel and wrought-iron pipe	61
Table 11.--Partial listing of typical capacity ratings and data for finned tube coils	62
Table 12.--Typical partial listing of capacity ratings for unit coolers	65

C. F. T. H. L.
FISH TECHNOLOGY EXPERIMENT STATION,
Mace Bazaar, MANGALORE-1.

INTRODUCTION

Fish are frozen and stored in both public and private cold-storage plants. In large fishing ports such as Gloucester, Boston, and Seattle, there are many public cold-storage plants capable of handling the tremendous daily influx of fish. In small seaports, however, the infrequent and limited supply of fish does not warrant the expense of a large public cold-storage plant. Many of the fish producers in the smaller seaports therefore have to maintain their own freezing and storage facilities.

The many different types of fishery products that are produced from the various species of fish found in the oceans, lakes, and rivers of this country require considerable differences in handling, freezing, and cold-storage techniques. For example, large fish such as salmon, tuna and halibut are usually frozen, glazed, and stored in-the-round and then reglazed at periodic intervals; whereas smaller fish such as cod and haddock are usually filleted, and the fillets are packaged, frozen, and stored in cardboard cartons.

The differences in handling, freezing, and storing various fishery products, the extra labor required in freezing and glazing round fish, and the aversion to storing unpackaged fish with other frozen materials cause considerable reluctance on the part of the operators of public cold-storage plants to freeze and store certain fishery products. This reluctance, in addition to the need for immediate freezing, has made it almost mandatory that individual fish producers have at least limited freezing and cold-storage facilities.

The preparation of complete specifications for a particular installation will require the combined efforts of company personnel, construction and refrigeration engineers, local health and building inspectors, and many others. It will therefore suffice here to mention some of the factors that should be considered in constructing a new cold storage, remodeling an existing plant, or selecting a public cold storage.

The following is a discussion of some of the more important of these factors: (1) plant location, (2) design and construction, and (3) product environment. A discussion dealing with the calculation of refrigeration requirements has also been included.

LOCATION

A cold-storage plant to be used for freezing and storing fishery products should be located so as to have accessibility to the wharves where the fishing boats dock, to fish-processing plants, and to adequate facilities for rail and truck transportation. The unavailability of land or its high cost in some densely populated seaboard towns, however, has resulted in the construction of cold-storage plants in the outlying districts relatively far from the wharves or processing plants. The wide

use of refrigerated trucks for local fish shipments, thereby making it possible to transport fish easily from the processing plant to the local freezer, has also been a factor in determining the location of the cold-storage plant.

In some cold-storage plants, particular types of fishery products, such as breaded fish sticks or breaded shrimp are frozen and stored. These plants are usually located adjacent to the processing plant, thereby enabling the processor to convey his product directly into the cold-storage plant for immediate freezing and subsequent storage.

As these examples indicate, the location of a cold-storage plant depends on many factors. Some of the more important of these that should be given consideration when the construction of a cold-storage plant to handle fishery products is contemplated are:

1. The source of fish supply.
2. The type of fishery product to be frozen and stored.
3. The facilities for rail and truck transportation.
4. The available labor supply.
5. The possibility of using sea or river water as cooling agents in the refrigeration condensers.
6. The cost of power.
7. The cost of land.
8. The taxes and miscellaneous costs.

DESIGN AND CONSTRUCTION

A refrigerated warehouse consists of a structure within an envelope of insulating and moisture-proofing material. The inside of this structure is divided into a number of rooms that are maintained at a predetermined temperature by use of adequate refrigeration equipment. To provide maximum operating efficiency, the walls, floors, and ceilings of cold-storage warehouses or of small private cold rooms must be of sturdy, tight construction.

It is beyond the scope of this leaflet to describe the different methods of construction that are used by engineering contractors to obtain a sturdy and tight warehouse or cold-storage room. Only those general requirements of basic design and construction that will acquaint the reader, contemplating such construction, with the subject sufficiently to enable him to discuss his needs intelligently with the engineers who specialize in this field will be discussed here. The discussion will include a description of the general design features as they pertain to refrigerated storage areas. Also, some of the more important specific design features that are common to all types of refrigerated warehouses, both large and small, will be included.

General Design Features

In the planning of a cold-storage plant, sufficient space must be allocated for efficient freezing, handling, and storing of the different types of fishery products peculiar to the geographical area. In addition, auxiliary space is also necessary for the refrigeration equipment, machine shop, elevators, offices, locker rooms, and facilities for loading and unloading. The general arrangement of the space within the plant must allow a smooth flow of the various products from loading platforms to freezer and then to the individual cold-storage rooms. The amount of space actually allocated for handling, freezing, and storing depends to a large extent on the type of products to be handled, whereas the auxiliary space depends on the over-all size and capacity of the warehouse.

The amount of space to be allocated for handling, freezing, and storing of the various types of fishery products varies considerably. A fishery cold-storage warehouse located in Seattle and designed to handle large amounts of round fish such as halibut, salmon, and tuna, for example, should have sufficient space for properly washing and glazing the fish. These fish are usually stored in-the-round one on top of the other in the cold-storage rooms. The additional washing and glazing operations together with the method of stacking in the cold rooms result not only in increased space requirements but also in a slower flow of fish in and out of the freezer than is found with packaged fish.

Fishery cold-storage plants located in the Boston and Gloucester areas are designed to handle large amounts of packaged fishery products and relatively small amounts of round fish. In these areas, the space necessary for washing and glazing the fish is considerably less than that required in a cold-storage plant in the Seattle area. In handling packaged products, however, additional space is necessary to allow a fast movement of the products into and out of the freezer.

With a small cold-storage room located within the processing plant, a fast flow of materials is sometimes sacrificed to obtain maximum utilization of the available space. Also, this particular type of operation does not usually warrant an investment in the equipment necessary for palletization. Products in the small cold-storage room are generally loaded on skids, which are moved into the freezer by hand trucks. The product is then usually unloaded and stacked by hand.

Frozen fish are stored in public cold-storage warehouses of the multistory, one-story, and modified one-story types, and in walk-in freezers located in the local seafood processing plants. Each of these refrigerated storage areas possess certain inherent advantages and disadvantages that should be considered by an operator planning on building a new plant or on making changes and improvements in an old one. The following is a discussion of some of the general design features that

apply to refrigerated warehouses and storage areas.

Multistory Warehouse

The first refrigerated warehouses were of multistory construction (figure 1) consisting of a basement and of 3 to 12 floors. Many of these warehouses were designed to freeze and store a particular type of product, such as fish or meat, rather than a diversity of products. The limited refrigerated transportation facilities, the high cost of land within densely populated seaboard towns, the general construction techniques of the period, and the then low cost of labor were all factors that contributed to the design of the multistory building.



Figure 1.—A multistory warehouse. This warehouse is used to store meat and fishery products. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

Multistory warehouses used to freeze and store fishery products are usually designed with the refrigeration machinery located in the basement and the loading and unloading facilities located on the street and dock level. Freezer rooms of the sharp or air-blast type are generally located on the first floor adjacent to the receiving facilities or on the second floor, though in some plants, the freezers are located on higher floors.

If round fish are handled, the glazing and washing tanks are located in a refrigerated space maintained at temperatures only slightly above freezing. In some plants, the freezer is connected to the glazing and washing room by means of a chute. Thus, a steady flow of frozen fish from the freezer to the glazing room is attained. The various floors are serviced by two or more elevators. A common arrangement is to have the elevator and freezer doors open into a common aisle maintained at temperatures just above freezing. In some plants, the elevators open into non-refrigerated spaces at the street-level loading platform and then into refrigerated spaces at 0° F. in the upper floors. This arrangement can result in frost accumulation on the cables of the elevator thereby impairing its operation. For best design, the elevator shaft should (1)

open, on all floors, into refrigerated spaces maintained at temperatures above freezing or (2) open, on all floors, into refrigerator spaces maintained at temperatures below freezing.

The construction of most multistory warehouses came before the development of power lift trucks. The height of the storage rooms therefore had to be such as would enable products to be efficiently stacked by hand. The height of most cold-storage rooms within such warehouses is between 10 to 12 feet, with piling heights of $7\frac{1}{2}$ to 10 feet.

Handling of packaged fishery products within a typical nonpalletized multistory building involves (1) moving by a suitable lift truck the product, which is loaded on skids, from the common carrier to the receiving room on the street floor; (2) moving the product from skids onto blast-freezer carts and moving the carts into the freezer; (3) removing frozen products from the freezer and cartoning packaged products; (4) loading cartoned, packaged products onto skids and moving the skids by a lift truck to the storage room; and (5) piling products within the storage room by hand. If round fish are handled, the operation is much the same as above except that the fish are frozen in a sharp freezer and then sent to a glazing room. Once glazed, they are either packed in wooden boxes or kept separated and transferred to a storage room (figure 2). In the handling of round fish, periodic reglazing is necessary to reduce dehydration during storage.

It is obvious from the above that considerable labor is involved in freezing and storing the product in a multistory building. At the inception of refrigerated warehousing, this use of much

labor was not an important point because of the relatively low labor costs during that period. The increased cost of labor throughout the years, however, has resulted in a proportional rise in the costs of product handling. This increase in product-handling costs together with the development of mechanical handling equipment has led to the construction of the



Figure 2.—Storage of mackerel in a multistory warehouse. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

one-story and modified one-story, completely palletized warehouses. The advantages of a non-palletized multistory warehouse, such as (1) the high ratio of product-storage space to gross-refrigerated space and (2) the low insulation costs, have been greatly outweighed by (1) the high cost of handling and (2) the slow movement of products within the warehouse.

To overcome these disadvantages, some operators have converted their multistory buildings to a palletized-type operation (figure 3). This conversion has been accomplished by using light-weight mechanical lift trucks and stacking products one or two pallets high—usually about $6\frac{1}{2}$



Figure 3.—Handling frozen products in a converted palletized multistory warehouse.

Note the low piling heights and the close column spacing. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

feet. The size of the pallet to be used is governed largely by the spacing of the columns within the building and the size of the door openings both in the storage room and in the common carrier. The conversion to a palletized operation from a non-palletized one reduces the labor necessary to handle the products by about 50 percent.

The decision to convert a warehouse to palletization is usually arrived at through a study of the initial modification cost and the possible reduction in continued handling costs. In a building of the older type, the cost of reinforcing the floors and elevators to carry the additional load would probably be too high to warrant the conversion. In a multistory building of the newer type, however, the elevators and floors might be strong enough to support the additional load of the mechanical fork trucks and pallets. In this instance, the reduced handling cost might offset the cost of conversion.

Extensive work in the development of smaller and lighter mechanical lift trucks is presently taking place. Such a truck will contribute greatly to the conversion of the nonpalletized multistory warehouses.

One-Story and Modified One-Story Warehouse

The increase in the consumption of frozen foods within recent years has greatly influenced the design of cold-storage warehouses. Whereas many of the first refrigerated warehouses were designed to store a particular type of frozen product, the new-type warehouses are designed to store a wide range of products--such as Pizza pies, canned soups, packaged vegetables, and packaged fish. To facilitate fast handling of these different types of frozen foods at a minimum cost, the new types of cold-storage warehouses employ mechanical handling equipment (figure 4) and automatic labor-saving and safety devices.

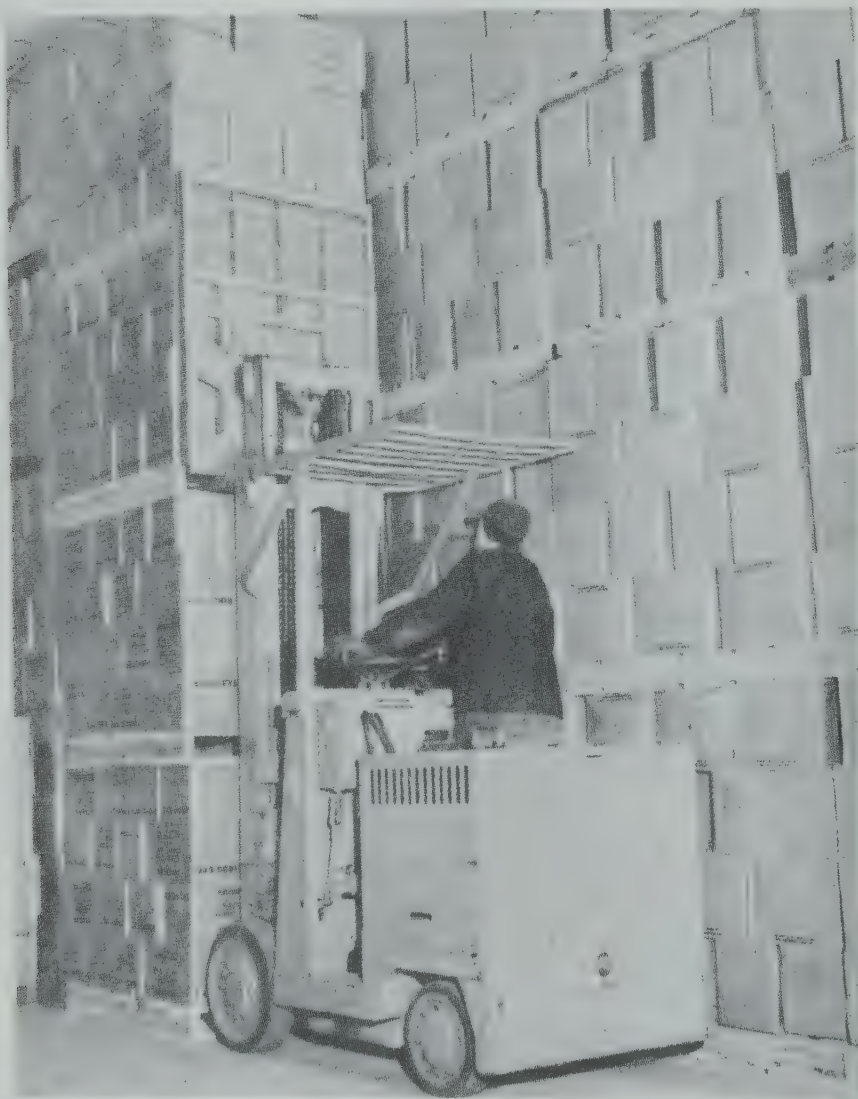


Figure 4.--A fork lift truck handling frozen products in a refrigerated warehouse. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

In the planning of such a warehouse, storage space is usually sacrificed in favor of a completely palletized operation. Freezing facilities are in some instances reduced because of (1) the increased cost of handling and (2) the ability of the individual processor to freeze his own products. Also, usually little or no provisions are made for storing products requiring special attention--such as round fish, which require periodic reglazing during storage. The convenient location in the city is often waived in favor of greater transportation facilities, lower cost of land, and lower taxes in the suburban areas. These considerations and many more are reflected in the design of the one-story and modified one-story warehouses of today.

One-story warehouse.--

The one-story warehouse is usually constructed on a base slab or on piles extending 3 to 4 feet above the ground. In the first case, heating coils or a series of warm-air ducts are provided under the base slab in order to prevent heaving of the floor due to freezing of the moisture in the ground. In the second case, the ventilated air space

carries the cold air away from the ground surface. The buildings are generally made of brick, which forms a complete envelope around the insulation. In some instances, concrete ceilings have been replaced by insulation of the loose or rigid type.

One design of a single-story warehouse features a rectangular building over 400 feet square with a capacity of 2,000,000 cubic feet of refrigerated space at -5° to -10° F., with facilities for unloading 20 railroad cars and 40 large trailers. The railroad and truck unloading platforms are connected by a wide traffic aisle. On each side of the aisle is a large cold-storage room with a capacity of over 1,000,000 cubic feet. Each storage room is serviced through a large vestibule with flapper doors at both ends. Complete mechanical palletization throughout permits the products to be piled 18 feet high in a room that is 20 feet high. Aisles 12 feet wide within the storage rooms are necessary for the large 4,000-pound-capacity fork lift trucks employed. Special crates that clamp over the pallets prevent the crushing of the less dense products when they are being stacked. Other features of this plant are (1) a -40° F. blast freezing room with a capacity of 100,000 pounds of products every 15 hours, (2) a large cooler room, (3) finned-pipe coils located over the aisles to give maximum product piling, (4) elevated truck ramps, (5) warm oil circulating in pipes in the base slab to prevent frost heaving of the floor, (6) an automatic temperature recorder that records temperatures throughout the storage area of the plant at predetermined time intervals, and (7) outside electric plug-in receptacles for the motors driving the refrigeration compressors on trailer trucks.

In a one-story warehouse such as that described above, packaged products are handled almost exclusively. The products to be frozen are usually received loaded on pallets with dunnage between each row of packages. This dunnage insures proper air circulation around products during freezing. The pallets are moved from the trailer truck into the freezer by a fork lift truck. After the products have been frozen, they are removed from the freezer and stacked on another pallet. A reinforced wooden basket is clamped over the pallets to prevent crushing of the less dense products when stacked. The loaded pallet is then moved to the desired location within the cold-storage room.

If the products are already frozen upon arrival at the plant, the fork lift truck transports the loaded pallets from the railroad cars or trailer trucks to within the plant for storage (figure 5). The loaded pallets that are to be located on the lower half of a pile, however, must be equipped with the reinforced wooden baskets previously described. This procedure involves extra handling that would not be necessary in rooms having lower ceilings.



Figure 5.--Unloading frozen products from a refrigerated truck. Note self-leveling dock ramp which meets truck's tail gate. (Photo courtesy of Industrial Refrigeration)

The single-story warehouse, although possessing the advantage of fast handling of products, with small labor costs and large unloading facilities for refrigerated trucks and railroad cars, does have certain disadvantages some of which are (1) long horizontal distances to move products, (2) need for special crates to prevent the less dense products from being crushed because of high piling heights, (3) treatment of floor below freezers to prevent the ground from heaving, (4) lost storage space because of wide aisles necessary for fork lift trucks, (5) high amount of

insulation required, and (6) high cost of the land in relation to the capacity of the building.

Modified one-story warehouse.--The disadvantages of the one-story warehouse have led to the design and construction of the modified one-story warehouse (figure 6). The construction techniques used in this

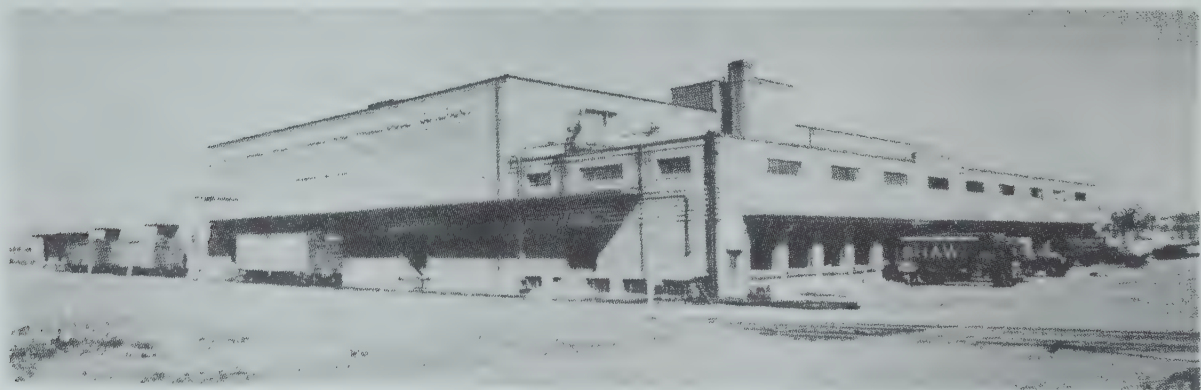


Figure 6.--A modified one-story warehouse. Note the different heights of the buildings and the rail and truck unloading facilities. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

building differ very little from those employed in the one-story warehouse, the principal design differences being in the use of two floors

with different piling heights and, in some cases, a mezzanine floor with piling heights only one pallet high. Such an arrangement gives more economical storage and a greater versatility in handling than is possible in the one-story warehouse, where all products are piled to the same height.

One design of a modified one-story warehouse with a total refrigerated space of over 2 million cubic feet features a two-story building with a mezzanine floor connected to a single-story building to form one complete unit. A service building--which provides space for the offices, power plant, and truck receiving and shipping rooms--is joined to the two-story building. The three buildings together comprise one complete warehouse unit.

The first floor of this combination of two-story and single-story buildings accommodates (1) two large cold-storage rooms with a piling height of 16 feet and of $16\frac{1}{2}$ feet, respectively, (2) a cold-storage area under the mezzanine for break-up rooms, and (3) space on the mezzanine with a piling height of $5\frac{1}{2}$ feet for storing small lots of the less dense products (figure 7). The first floor also contains a large refrigerated

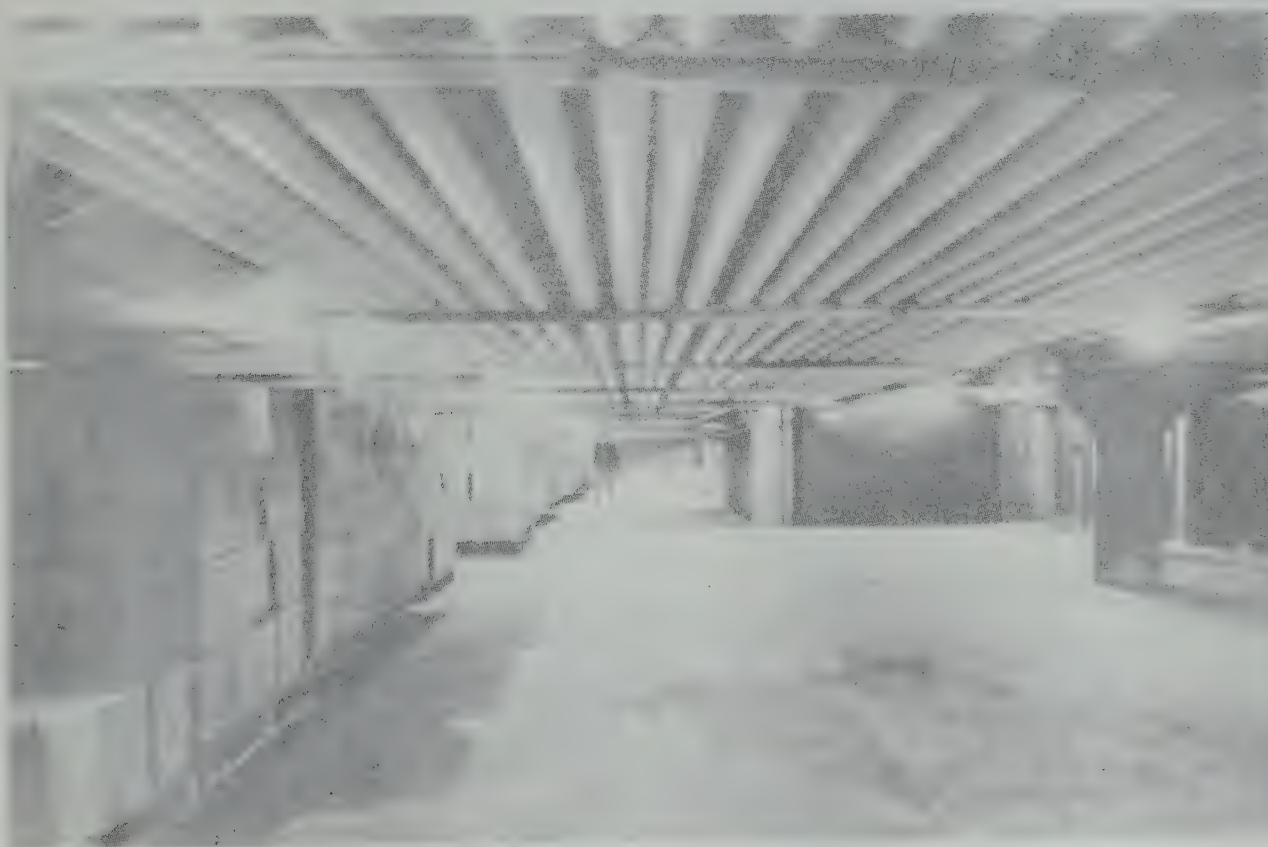


Figure 7.—Product storage on the mezzanine floor of a refrigerated warehouse. Note the low piling heights. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

receiving room running the length of the buildings. The receiving room has freezer doors opening into the cold-storage area, onto the truck unloading platform, and onto the railroad siding. Three blast-freezer rooms with a total capacity of 75,000 pounds of product per 8-hour day



Figure 8.—Unloading frozen products from a refrigerated railroad car. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

The above design, by use of mechanical fork lift trucks (figure 8), allows a smooth flow of material from railroad cars and refrigerated trailers into the receiving room, thence to the blast freezer, and finally to the cold-storage area most suitable for the particular product. The less dense products, such as fish sticks, are received in a frozen condition from the refrigerated carrier and transported by 2,000-pound-capacity fork lift trucks to the mezzanine area (figure 9) for storage; and denser products, such as frozen fish fillets and fish blocks, are carried from the refrigerated carrier to either the first or second floor cold-storage area by 4,000-pound-capacity fork lift trucks. The use

are also located on the first floor and can be filled directly from the receiving room.

The second floor of the building consists of one large cold-storage room at -5° F. with a piling height of 16 feet. This room is serviced by an elevator of 20,000-pound capacity, and the mezzanine is serviced by one of 10,000-pound capacity.



Figure 9.—View showing the first floor and mezzanine floor in a public warehouse. Note the fork lift truck on the first floor stacking products on the mezzanine floor. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

of the lower-capacity trucks in the mezzanine area makes it possible to limit the aisle to a width of 8 feet and the stacks to a height of one pallet. With the 4,000-pound-capacity truck in the other refrigerated areas, products may be stacked three to four pallets high with 12-foot-wide aisles (figure 10). This method of product storage eliminates the need for the special baskets required in the single-story building and gives efficient utilization of the space for product storage.

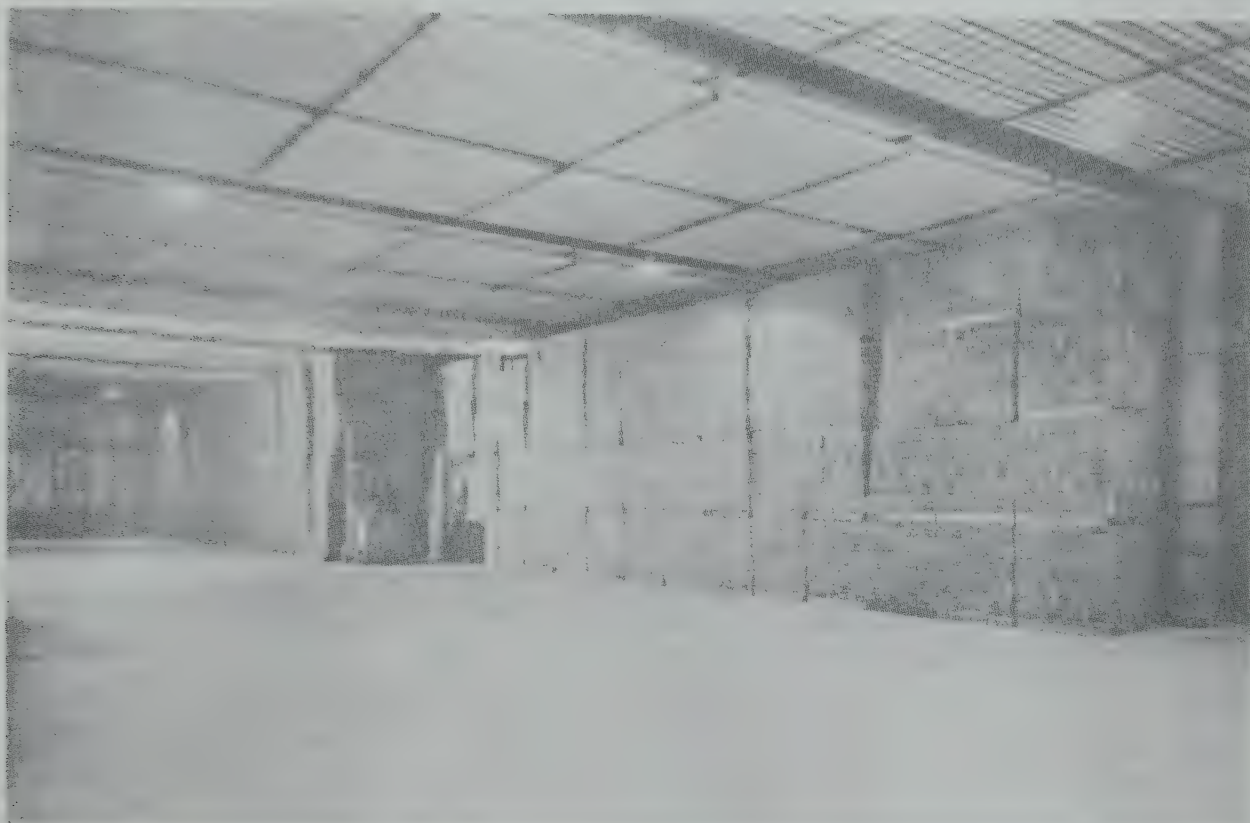


Figure 10.—Product storage on the first floor of a modified one-story warehouse. (Photo courtesy of Quincy Market Cold Storage and Warehouse Co.)

Another feature of this plant is the use of reflectant insulation material in the walls and ceiling of one of the buildings. This insulation is built up of 8 layers of aluminum sheets with a $\frac{5}{8}$ -inch dead air space between each layer. These sheets are stapled to treated wood screeds running in both vertical and horizontal directions. The outside sheet is sealed with metallic lead, which provides an effective vapor seal. A multistage potentiometer is used to measure the temperatures in the air space between each successive layer of reflectant insulation material.

The inside sheet of insulation is a heavy-gauge steel sheet, which is galvanized and treated with an aluminum lacquer for added protection. Additional structural members are provided on the walls to prevent any possible damage from fork lift trucks. The roof consists of a concrete slab with the same type of reflectant insulation as is used in the walls. The design of the roof is such that it will support and retain a 6-inch-deep layer of water when required. This layer of water reduces the

effective refrigeration load in hot weather.

The temperature within the cold-storage rooms is held at -5° F. by Diesel-driven compressors of variable speed. These compressors maintain a constant ammonia suction pressure, making it possible to keep the room temperature from rising more than 5° F. above that of the cold brine circulating through the overhead pipe coils. This small temperature differential results in a high relative humidity, which contributes greatly to the storage life of the products. Other features of this plant are its wide, light-weight flapper doors, completely automatic refrigeration machinery, and hydraulic platforms for facilitating the unloading of the trailer trucks. Heating coils containing a glycol solution at 50° F. are installed below the floor slab to prevent frost heaving. The plant also has an alarm system, which is connected to the local telegraph office, to indicate fire, machinery breakdown, or forced entry of the premises.

A modified single-story cold-storage plant of over a million cubic feet to be used exclusively for the storage of frozen fishery products has recently been constructed in Gloucester, Massachusetts. This is one of the most modern fishery cold-storage warehouses in the world. The site of construction is such that it is possible to unload frozen fish directly from vessels and trailer trucks. The storage facilities consist of two large rooms at -5° F. on separate levels to provide maximum utilization of space with a minimum amount of handling. All of the modern labor-saving and safety devices mentioned previously are being utilized.

Walk-in Freezers and Coolers

Walk-in freezers and coolers are found in fish-processing plants, fish markets, and many other places handling fresh or frozen fishery products. The rooms comprising the freezers and coolers are similar to those used in large public warehouses, inasmuch as they are completely enclosed by suitable insulation and moisture-proofing material and are cooled by bare pipe coils, finned pipe coils, refrigerated plates, or blower-type unit coolers. The walk-in cooler or freezer, however, differs somewhat from the large public cold-storage warehouses because of its size and method of product storage and handling.

Fishery products usually are stored in the walk-in freezer (1) on shelves, (2) in cardboard or wooden boxes, or (3) in the round, stacked individually. The exact method of storage employed depends on the specific application. A small dealer selling fish chowder and other frozen specialty items, for example, might have the various products arranged on shelves within the freezer. This arrangement will enable him to select immediately the particular product desired by the customer. A fish processor located in New England, as another example, might store iced fresh fish in wooden boxes in the cooler at temperatures of 35° to

40° F. prior to processing. The fish, after being processed in the form of packaged fillets, would be frozen and then packed into cartons. These cartons would then be loaded on to skids and moved into the freezer by a small hand truck. The cartons, once in the freezer, would be unloaded and stacked by hand. If round fish were to be handled, they would be glazed and stored on shelves, in wooden boxes, or merely stacked one on top of the other.

In the walk-in freezer, the piling height for packaged products should be between $7\frac{1}{2}$ and 10 feet, with at least 1 foot clearance between the cooling coils and the top of the products. Piling heights in excess of 10 feet will result in extreme difficulty in product handling. In large cold-storage rooms, however, piling heights of 20 feet can be utilized if palletization and fork lift trucks are employed.

A designer, in allocating the proper amount of space for the storage of a product, must know its density. Such products as fish sticks and fish fillets have densities of approximately 25 to 30 pounds per cubic foot and of 55 to 60 pounds per cubic foot, respectively. Round fish stored in wooden boxes or stacked individually within the freezer have densities ranging from 30 to 35 pounds per cubic foot. If round fish of an average weight of 10 pounds are stored on shelves, about 1 square foot of shelf space should be allocated for each $7\frac{1}{2}$ pounds of fish. In the storage of 10-pound $2\frac{1}{2}$ -inch-thick packages of fish fillets, about 1 square foot of shelf space should be allocated for each 10 to 11 pounds of fish.

The location of the cooler and freezer should be such that the cooler provides an anteroom for the freezer. With such an arrangement, the opening of the freezer door will result in the infiltration into the freezer of air at 35° to 40° F. from the cooler, rather than of the warm relatively humid air from the processing room. The prevention of the entrance of the warmer air when personnel enter and leave the freezer minimizes (1) frost accumulation on the coils and (2) temperature rise within the freezer.

Specific Design Features

Refrigerated Surfaces

The refrigerated surfaces consist of bare pipe coils, finned pipe coils, refrigerated plates, or blower-type unit coolers. The following gives a description of these refrigerated surfaces and a discussion of their relative merits.

Bare pipe coils.--Bare pipe coils consist of steel pipe that is fabricated to form continuous coils. These coils are suspended from the ceiling of the freezer by means of suitable hangers. Air space from 3 to 6 inches should be left between the top of the pipe coil and the ceiling to permit proper air circulation. The particular size of pipe

used varies from 1 to 2 inches in diameter, depending on the desired capacity of the specific installation.

A refrigerant, such as ammonia or Freon-12, is allowed to expand through the pipes, in the direct expansion system; and a prechilled calcium-chloride brine solution is circulated through the pipes, in the indirect-expansion system (see "Evaporators," section 2). The advantages of expanding the refrigerant directly in the pipe coils are (1) a high rate of heat transfer and (2) a lower initial cost. The principal disadvantage of the direct-expansion system employing ammonia is the possible spoilage of product and the danger to personnel in event of pipe leakage or rupture. The use of an indirect-expansion system employing calcium-chloride brine circulating through the coils results in a slower rate of heat transfer and a higher initial cost but has the advantage of maintaining a more constant temperature within the storage room than would normally be possible with a direct-expansion system.

Bare pipe coils have the advantages of being durable, relatively inexpensive, and easily available but have the major disadvantages of small amount of cooling surface per linear foot of pipe, high cost of installation, and high weight per square foot of actual cooling surface.

Finned pipe coils.—Finned pipe coils have been used to a large extent within the last decade in cold-storage warehouses. Ammonia, Freon-12, or a calcium-chloride brine solution is usually circulated through the coils in order to provide the necessary refrigeration effect. A finned pipe coil has considerably more cooling surface per linear foot than has a bare pipe coil. One type of commercial finned pipe coil consisting of fins 7 inches square and 1 inch apart and bonded on a 2-inch-diameter steel pipe, for example, has 8.1 square feet of cooling surface per linear foot as compared with 0.62 square feet of cooling surface per linear foot for standard 2-inch-diameter steel pipe. Such a finned pipe coil has a heat transfer rate of 1.2 B.t.u. per hour per °F. per square foot of cooling surface as compared with a heat transfer rate of 2.0 B.t.u. per hour per °F. per square foot of cooling surface for standard 2-inch pipe. Since, however, the finned pipe coil has such a large cooling surface per linear foot, it is obvious that, for a particular installation, the total linear feet of finned pipe coils required to accomplish the necessary refrigeration effect would be considerably less than that required with bare pipe coils.

Inasmuch as the number of linear feet of finned pipe coil required is relatively small, most of the finned pipe coils can be located over the aisles of the cold-storage room. This location permits higher stacking of products in the storage area and prevents the dripping of water on the products when the pipes are defrosted. The fins of the pipe coils should be at least 1-inch apart because closer spacing will result in excessive frost build-up, necessitating frequent defrosting. The finned pipe coil loses more efficiency due to frost build-up than does either the bare pipe coil or the refrigerated plate.

Refrigerated plates.--Refrigerated plates are essentially a modification of the bare pipe coil. The simplest construction involves the welding of a suitable metal plate to one side of the coil. A better method, however, is to weld or solder two metal plates on each side. These plates are then crimped together on all sides and welded or soldered. The result, essentially, is a flattened pipe coil with a large amount of cooling surface.

A predetermined number of plates are connected together in parallel with common inlet and outlet pipes so as to form a complete bank of plates. These plates are suspended vertically from the ceiling of the refrigerated space in much the same manner as are the bare pipe coils. A refrigerant such as ammonia, Freon 12, or calcium-chloride brine is used to provide the necessary refrigeration effect. The heat-transfer rate per square foot of cooling surface is similar to that of bare pipe coils. The size of the plate is such, however, that there is a large amount of cooling surface per linear foot. In addition, such plates possess the advantage of losing very little efficiency due to frost accumulation, and of being very easy to defrost and to install. Refrigerated plates are used to a large extent in walk-in freezers and to some extent in large cold-storage plants.

Blower-type unit coolers.--The blower-type unit cooler consists essentially of a bank of bare or finned pipe coils with a fan to circulate the air within the storage room. This type of cooler is suitable for use in either a direct- or indirect-expansion system. In most installations, a direct-expansion system employing ammonia or Freon 12 is used because of its high efficiency and low initial cost.

Commercial blower-type unit coolers are of either the dry-pipe type or the spray type. The main difference between these two types is in the method of defrosting. In the dry-pipe type, defrosting is accomplished by the use of (1) water sprays, (2) circulation of hot refrigerant gas in the coils, or (3) electric heaters; whereas in the spray type, salt or glycol solutions are sprayed on the coils at periodic intervals to dissolve the frost. The salt or glycol solutions, after picking up the moisture from the dissolved frost on the coils, drain to a basin at the bottom of the cooling unit. These solutions are maintained at their proper strength by the addition of salt to the salt solution or by use of a concentrator with the glycol solution.

Since the unit cooler employs forced-air circulation, it is very important that the cooling surfaces of the units be of sufficient area so that the temperature differential between the circulating air and the refrigerant can be kept to 10° F. or less. The circulation of the air within a freezer using a unit cooler has a greater drying effect on the products than has the natural convection currents that are present in a freezer using bare pipe coils, finned pipe coils, or refrigerated

plates. It is therefore necessary to maintain a higher relative humidity in the air in a forced-air circulating system than in a natural-air circulating system. The actual amount of moisture withdrawn with each type of refrigerated surface, however, varies greatly with the particular installation. In all instances, adequate consideration should be given to the selection of the refrigerated surfaces to be used so that it will be possible to maintain a relatively high humidity within the freezer, thereby keeping the dehydration of the product at the absolute minimum.

Insulation

Function and properties of insulation.--The function of insulation is to restrict the flow of heat into the refrigerated room from the outside surroundings. The ability of a particular type of insulation to resist the flow of heat by conduction from the warm side to the cold side is measured by the thermal conductivity of the material. (A discussion of thermal conductivities of insulating materials and of methods of calculating the heat gained through the insulation in refrigerated rooms is given later in this section.)

The three types of insulation suitable for use in refrigerated warehouses are (1) loose or fill material, (2) rigid board or block materials, and (3) reflectant materials. Within each of these three types, the available commercial products are numerous and offer a wide selection for a specific installation.

An insulation material for use in a cold-storage room should possess the following properties:

1. Low thermal conductivity.
2. Low water absorption.
3. Low water-vapor transmission.
4. Low inflammability.
5. Good mechanical properties.
6. Resistance to fungi and vermin.
7. Be easily cut, shaped, and glued, etc., in installing.

Selection of insulation.--Some of the factors to be considered in selecting insulating materials are (1) initial cost; (2) installation cost; (3) operating, maintenance, repair, and depreciation costs; (4) local weather conditions, temperature, and humidity; (5) type of product to be stored; (6) permanence of structure; and (7) temperature in cold-storage rooms.

The most satisfactory insulating material is the one that offers the best combination of characteristics desirable for a specific set of local conditions, at the most economical cost both initially and operations-wise. No one insulating material is superior in all respects. For example, one rigid type of insulation material--although offering

the advantages of low thermal conductivity, high structural strength, and ease of installation--possesses the disadvantages of high density and the absorption of water. On the other hand, a competitive product that offers a higher resistance to heat transfer, a lower density, and imperviousness to water requires the use of special construction techniques for installation.

Application of insulation.--After the proper insulating material has been selected, careful consideration must be given to the method of applying it to the walls, ceiling, and floor of the refrigerated enclosure. The main object is to obtain a tight insulated envelope around the periphery of the cold-storage room. In applying the insulation, an adequate vapor seal must be used between the outer wall and the first layer of insulation. This vapor seal is necessary to restrict the passage of water vapor from the outside through the walls, ceiling, and floor 1/ of the refrigerated room.

If the insulation is not properly applied or if an ineffective vapor seal is used, water vapor will permeate the vapor barrier and, condensing to water, will freeze within the insulation. This formation of ice greatly decreases the insulating value of the material. In addition, some of the water vapor continues to migrate through the walls and deposits on the refrigerated coils within the room, necessitating frequent defrosting of the coils.

The thickness of insulation used is closely related to tax structure. In a given installation, for example, it may be less expensive to adopt the "minimum" safe insulation for temperatures and products and to expect larger power and maintenance bills, since these latter expenses come out of revenues earned before taxes are calculated, whereas the amortization of the building is after taxes. A table at the end of this section gives recommended insulation thicknesses for refrigerated warehouses located in various areas of the country.

Freezer Floors

In the older multistory warehouses, cooler rooms or nonrefrigerated rooms were located on the ground floor. Precautions against frost heaving of the floor were therefore not necessary. In recent years, however, the utilization of the ground floor for low-temperature storage has resulted in floor heaving and buckling in many warehouses.

Floor heaving is the result of the cumulative effects of ice pockets formed under the insulated floor as the ground is chilled below freezing. This formation of ice exerts an upward force on the floor slab, resulting in cracking and bulging of the floor (figure 11). The rate of ice

1/ A vapor seal is not used if the cold storage room is on the ground floor. (See "Freezer Floors.")

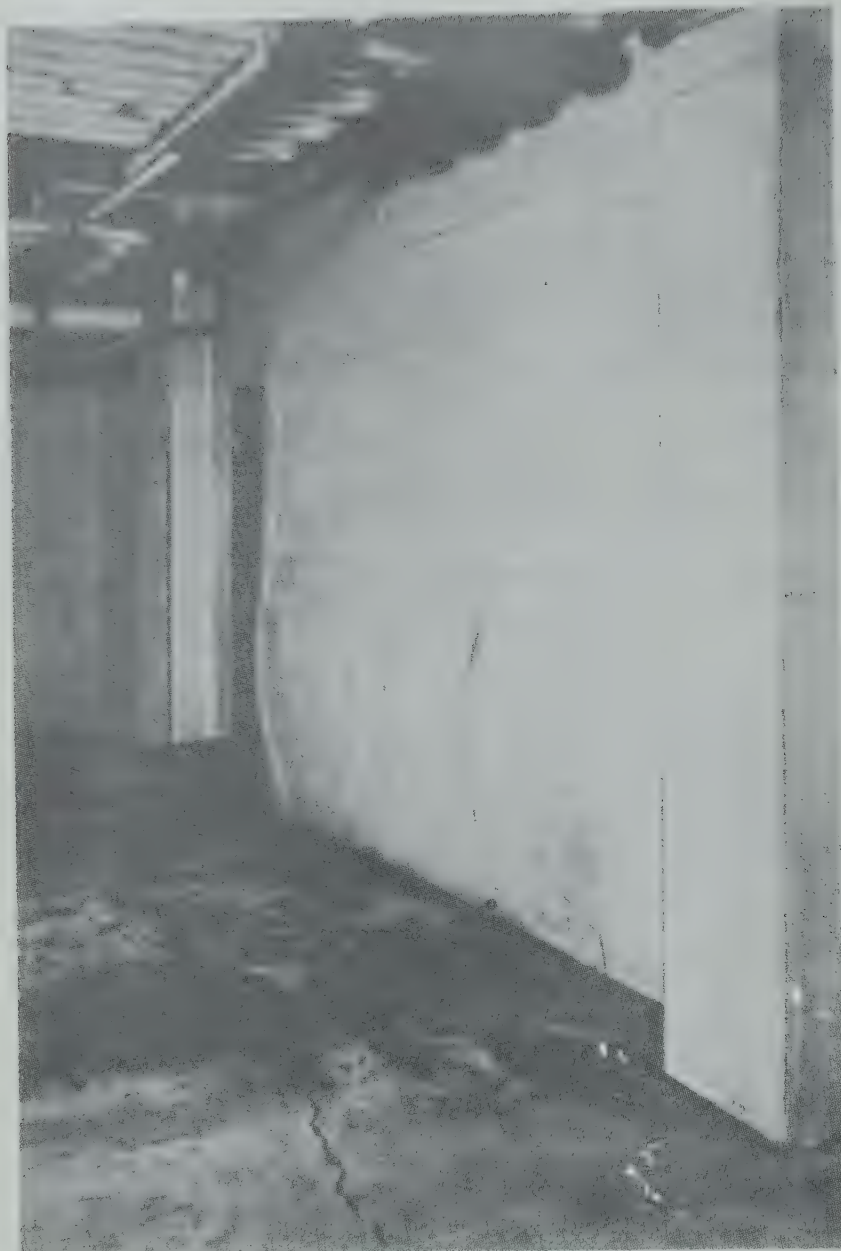


Figure 11.--Cracking and bulging of a freezer floor. (Photo courtesy of Armstrong Cork Co.)

formation in the ground depends on (1) the temperature of the cold-storage room, (2) the insulation thickness, (3) the characteristics of the soil, and (4) the height of the water level in the particular area.

The usual design of a freezer floor consists of a layer of gravel, on the surface of the ground, supporting (1) a concrete slab covered with a thick layer of insulation and (2) a concrete wearing-slab. The cold surface of the freezer floor causes a continuous migration of moisture from the lower layer of ground to the upper layer of ground and into the cold-storage room. A moisture-vapor-proof material should not be used between the floor slab and the insulation because the use of this material will result in trapping moisture in the surface layer of ground and will greatly accelerate frost heaving. A thick insulation material, on the other hand, will reduce the depth of the freezing zone and is there-

fore to be recommended.

In areas where the water table is low and the soil is very dry, use of sufficient amount of fill and suitable insulation might prevent frost heaving of the ground. To provide a positive method of protection, however, heat must be added to the ground by any one of several methods. A heated oil solution may be circulated through pipe coils in the slab below the insulation, for example, or electric heating elements may be enclosed in a conduit in the bottom slab. In another system, flues are formed in the ground by hollow tile, and the use of natural or forced air circulation through these flues furnishes the necessary heat to prevent the ground from freezing. A thermostatic control employed in the above systems permits maintenance of proper temperatures in the ground at all times.

Some cold-storage plants are constructed on piles, with the floor being located 4 to 5 feet above the ground level. If the floor area is relatively small, natural air circulation will give adequate protection against ground freezing. For large floor areas, however, forced air circulation utilizing one or more fans is necessary.

In the selection of a particular method of preventing frost heaving, consideration must be given to (1) initial cost, (2) operating cost, and (3) dependability of each particular system. The characteristics of the soil and the climatic conditions also affect this selection. Until adequate data are obtained on the causes of and the remedies for frost heaving, the owner must weigh the possible damage due to frost heaving against the increased cost of providing adequate protection.

Refrigerator Doors

Refrigerator doors are of the infitting, overlap, or sliding types. The thickness of insulation, hardware, and protective covering for each door varies with the particular installation.

Infitting or plug-type doors (figure 12) are relatively compact and



Figure 12.—An infitting freezer door equipped with a set of flapper doors to minimize loss of cold air while the storage room is being loaded and unloaded. (Photo courtesy of Jamison Cold Storage Door Co.)

light. Air leakage, because of the small amount of sealing area and of the build up of frost on the sides of the door, has been a problem in the past. In recent years, however, the construction of doors with a double seal, on inside and outside, and the use of suitable electric heating elements have overcome these difficulties. The infitting door is widely used for cooler rooms and is also suitable for 0° F. freezer rooms.

The overlap door (figure 13) was designed to eliminate some of the inherent disadvantages of the infitting door when used for low-temperature applications (0° to -60° F.). This door has a wide gasket to insure a tight seal. The use of an electric heating element in the door frame is recommended to prevent frost accumulation on the area in contact with the gasket. This door is widely used in commercial cold-storage warehouses and in quick freezers operating at temperatures as low as -60°F.

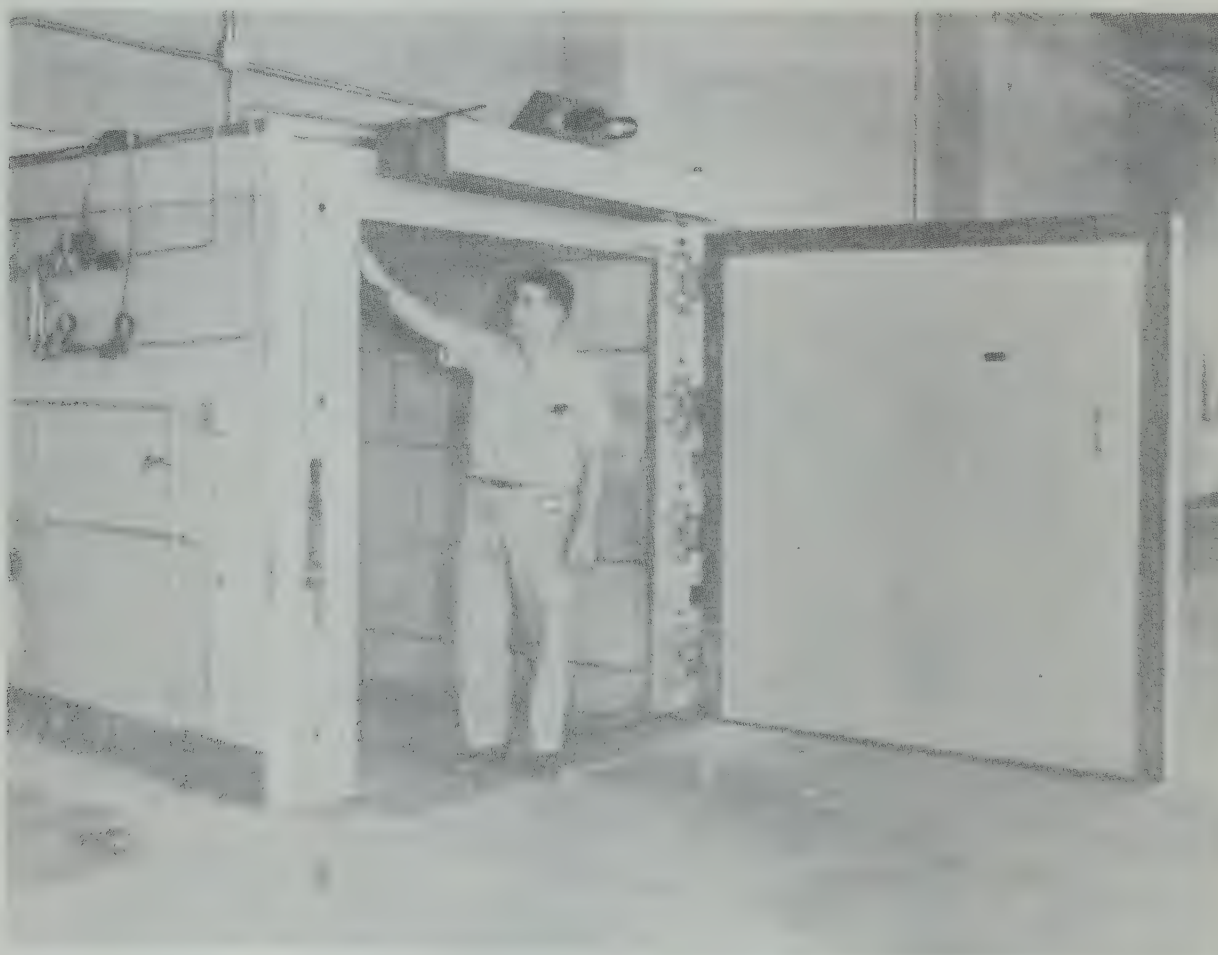


Figure 13.--An overlap freezer door with heater cables embedded beneath the cover plate on all three sides of the door frame. (Photo courtesy of Jamison Cold Storage Door Co.)

The sliding door is basically an overlap-type door suspended by pulleys, which ride on a track located above the door. A suitable linkage arrangement permits the door to move sideways whenever it is desired. This door offers the advantage of more usable floor space, elimination of heavy load on the door frame, and ease of operation. The

quick opening and closing action of these doors makes a double vestibule door less necessary.

Most vestibules have a refrigerator door and, in addition, a set of flapper doors at the entrance of the vestibule and another set of flapper doors between the vestibule and the refrigerated storage area. These flapper doors are available in plywood or rubber.

The plywood doors are usually covered with protective galvanized metal sheathing to minimize possible damage. These doors, although having a relatively low initial cost, are subject to damage from fork lift trucks. Frost accumulation on the doors is also a problem.

The rubber doors have a higher initial cost than do the plywood doors. This increase in initial cost, however, is offset by the ability of the doors to withstand the heavy abuse of fork lift trucks and to resist the accumulation of frost.

PRODUCT ENVIRONMENT

The term product environment refers to the atmosphere surrounding the product during storage. In the storage of fishery products, the air within the cold-storage room must have (1) a low temperature, (2) a high relative humidity, and (3) a low velocity. The effects of the temperature, humidity, and velocity of the air on the storage life of fishery products is described in Fishery Leaflet 429, section 2. The following will therefore be limited to a discussion of some of the factors that should be considered in the design of a warehouse in order to obtain the optimum air temperature, relative humidity, and air circulation.

Temperature

For satisfactory storage of frozen fishery products, the temperature of the storage room should be kept at 0° F. or lower and should undergo as little fluctuation as is possible. Temperatures below 0° F., although greatly increasing the storage life of the product, do require more costly construction and equipment and may increase operating expenses as well.

The number of square feet of coil cooling surface largely determines the equipment-operating costs. A cold-storage room at 0° F. with an insufficient amount of cooling coils, for example, might require a coil temperature of -20° F. to furnish the necessary refrigeration effect, whereas another installation with a large cooling surface might require a coil temperature of only -5° F. to accomplish the same purpose. In the first example, the refrigeration system would have to operate at evaporator temperatures of -20° F., which would result in (1) higher initial cost of refrigeration machinery, (2) higher cost of operation,

and (3) lower cost of pipe coils. In the second example, the refrigeration system would have to operate at an evaporator temperature of -5°F. , which would result in (1) lower initial cost of refrigeration machinery, (2) lower cost of operation, and (3) higher cost of pipe coils.

As the temperature of the air decreases, the ability of the air to hold water also decreases. Air at 0°F. and at a relative humidity of 100 percent, for example, contains about three times more water than does air at -20°F. and at the same relative humidity. Therefore, for a given relative humidity, air at a lower temperature will absorb less moisture from the product than will air at a higher temperature.

Recent developments in the design of refrigeration equipment have made it possible to obtain cold-storage-room temperatures of -10°F. far more efficiently than was ever before thought possible. Anyone contemplating the construction of a refrigerated warehouse should therefore carefully weigh the increased refrigeration costs for lower temperatures against the return from the pronounced increase in storage life of the product.

Relative Humidity

When air containing moisture undergoes a drop in temperature at a constant pressure, a temperature will be reached at which condensation and precipitation of the moisture will occur. This temperature is the dew point. If the dew point is equal to the temperature as indicated by a standard thermometer (dry-bulb temperature), the air is completely saturated and has a relative humidity of 100 percent. If, however, the dew point is lower than the dry-bulb temperature, the air is only partially saturated and has a correspondingly lower relative humidity. These definitions are necessary for the following considerations of the factors affecting humidity levels in the refrigerated warehouse.

The moisture contained within the air exerts a certain vapor pressure, which is ordinarily measured in pounds per square inch (p.s.i.). Other factors being equal, completely saturated air at a high temperature will have a higher vapor pressure and will contain more moisture than will completely saturated air at a lower temperature.

In an empty refrigerated room in which the coil temperature is say at -10°F. and the room temperature is at 0°F. , condensation, on the coils, of the moisture in the air will occur until the dew point of the 0°F. air (dry-bulb temperature) within the freezer reaches -10°F. Air at 0°F. having a dew point of -10°F. exerts a vapor pressure of 0.0108 p.s.i. Correspondingly, if the air at 0°F. were completely saturated, it would have a dew point of 0°F. and exert a vapor pressure of 0.0188 p.s.i. The percent relative humidity is equal to the vapor pressure of the air within the room at its dew-point temperature (-10°F.) divided by the vapor pressure of completely saturated air at the dry-bulb temperature (0°F.).

This relationship is expressed by the formula:

$$H = \frac{P_1(100)}{P_2}$$

where H is the relative humidity, P_1 is the vapor pressure of water at the dew-point temperature, and P_2 is the vapor pressure of water at the dry-bulb temperature.

The use of this formula is illustrated in the following problem:

Sample Problem

In designing a cold-storage plant, a producer wishes to maintain the room at 0° F. and the cooling coils at -10° F. Assuming that the room is void of products, determine the percent relative humidity.

Because the room is empty, it can be assumed that the dew point of the air at 0° F. will be the same as the coil temperature, which is -10° F. From psychrometric tables (American Society of Refrigerating Engineers 1954), we find that P_1 is 0.0108 p.s.i. and P_2 is 0.0188 p.s.i. The relative humidity therefore is:

$$\frac{(0.0108)(100)}{0.0188} = 57.5 \text{ percent.}$$

If, however, the coil temperature were maintained at -5° F. instead of at -10° F., the dew point of the air would be -5° F. In this example, the relative humidity would be:

$$\frac{(0.0141)(100)}{0.0188} = 75 \text{ percent.}$$

The relative humidity in commercial freezers is 10 to 20 percent higher than are those indicated by the calculated figures above because of the evaporation of moisture from the product. In a freezer at 0° F. with a relative humidity of 75 percent and a pipe-coil temperature of -15° F., the moisture-vapor pressure within the package and in contact with the frozen fish would be 0.0188 p.s.i. The air in the freezer, however, would have a vapor pressure of 0.0141 p.s.i. and the moisture-vapor pressure at the coils would be 0.00825 p.s.i. These differences in vapor pressure result in migration of moisture from the air surrounding the product to the air of the room, thereby causing an increase in the humidity level. At the cold coils, the dew point drops, and the excess vapor condenses on the coils and deposits as frost.

A high relative humidity can be obtained by (1) adding moisture to the room, (2) increasing the cooling surface, or (3) employing the

jacketed principle.

Adding Moisture to the Room

The relative humidity can be greatly increased by spraying steam into the atmosphere within the refrigerated room. This method, however, is not very suitable because of (1) the accumulation of ice on the freezer floor due to the difficulty in saturating the air with all the water vapor in the steam and (2) the excessive accumulation of frost on the cooling coils. Cooke (1939) reported that it was possible to obtain a relative humidity of 95 percent by adding moisture to the room in such a manner that it would not accumulate on the cooling coils. In this method, the steam was atomized and injected into the atmosphere so as almost to saturate the air completely. The problem of frost accumulation on the cooling coils was overcome by continually spraying an ethylene glycol solution over the coils to absorb any moisture condensed on them. The moisture absorbed was then removed by heating the ethylene glycol and was returned to the freezer in the form of steam. Recent tests on a system of this type indicate that a doubling of the power consumption is necessary to raise the relative humidity of the room from 60 to 100 percent.

Increasing Surface Area of the Coil

As was mentioned previously, the temperature of the cooling coil and of the room largely determines the relative humidity. The sample problem illustrated that a high humidity can be obtained by maintaining a minimum difference between the temperature of the cooling coil and that of the air. The method of determining the amount of cooling-coil surface required for a particular installation is described later in this section in "How to Calculate Cold-Storage Requirements."

Cold-storage plants constructed within recent years have greatly increased the amount of cooling-coil surface over the once widely used ratio of 1 linear foot of 2-inch pipe coil per 6 cubic feet of storage space. The increase in the surface area of the coil together with the utilization of special insulation materials and construction techniques to minimize air infiltration has made it possible to obtain very high humidities in the modern cold-storage warehouse.

Jacketed Principle

In the jacketed system, cold air circulates through an enclosed space or jacket that completely surrounds the room. The outside surface of the jacket is lined with a suitable insulation that is 8 to 10 inches thick. The inside surface consists of the materials that comprise the walls, floor, and ceiling of the storage room. Vertical and longitudinal wooden members in the jacket are arranged so as to provide ducts that

distribute cold air in the proper amounts through various parts of the jacket. The jacket is a closed-duct system containing a set of finned-pipe or bare-pipe cooling coils to maintain the air at the proper temperature and a fan to provide the necessary air circulation through the ducts. The cold air circulating through these ducts maintains the inner storage room at a predetermined temperature by removing the heat that migrates through the insulated walls, ceiling, and floor before it can enter the refrigerated storage area.

With proper air circulation throughout the inner room, the difference between the temperature of the jacket walls and that of the room can be kept as small as 2° F. Owing to the small magnitude of this temperature differential, it is possible to maintain relative humidities as high as 98 percent in the storage space. Also, the air in the ducts does not enter the inner room; therefore, it cannot draw moisture away from the product. During operation, the moisture contained in the air within the duct is withdrawn by defrosting the cooling coils. Consequently, this air becomes very dry, resulting in very little frost accumulation on these coils.

A jacketed-type freezer was recently constructed at the Fish and Wildlife Service laboratory at East Boston, Massachusetts. Tests are presently being conducted to determine the effect of the jacketed principle on the storage life of fishery products and to gather engineering data in regard to the operation of the equipment.

Air Circulation

Rapid circulation of air within the cold-storage room will result in the withdrawal of moisture from the product. If a blower-type unit cooler is used to furnish the refrigeration effect, the air circulation must be kept at a minimum. This desired amount of circulation is accomplished by properly balancing the amount of cooling surface against the rate at which the air is moved by the fan. To minimize the drying effect due to the air circulation, a freezer employing a unit cooler with forced-air circulation must have a higher relative humidity than that required in a conventional still-air room.

In such a conventional still-air room, the temperature difference between the coil and the room determines the amount of circulation due to natural convection currents resulting from the difference in density between warm and cold air. Furthermore, an increase in this temperature difference causes a proportional increase in the moisture-vapor pressure differences, resulting in an additional increase in the natural circulation of air within the room. Conversely, a lowering of the temperature difference will result in a decrease in the differential between the moisture-vapor pressures, thereby causing slower movement of air. By proper proportioning of the amount of cooling surface area to the refrigerator load, the air circulation can thus be kept at a minimum.

CALCULATION OF THE COLD-STORAGE REQUIREMENTS OF FISH

In the calculation of the cold-storage requirements of fish, three of the basic considerations are (1) the rate of heat flow into the cold-storage room (heat-gain load), (2) the size of the evaporator needed to remove this heat, and (3) the size of the compressor needed to keep the system in operation.

The calculated heat-gain load of the cold-storage room determines the size of the compressor; and the size of the compressor selected, in turn, determines the size of the evaporator.

To enable the prospective builder to make a preliminary estimation of the cold-storage requirements for a particular service and thereby help him to discuss his needs intelligently with the refrigeration engineer or contractor upon whose recommendations he will ultimately rely, the remaining part of this section gives information on (1) how to calculate the heat-gain load in the cold-storage room, (2) how to calculate the size of the compressor, and (3) how to calculate the size of the evaporator. In addition, to show the interrelationships among these three sets of calculations, an overall illustrative problem is given.

HOW TO CALCULATE THE HEAT-GAIN LOAD IN THE COLD-STORAGE ROOM

In the calculation of the total heat-gain load (q') in the cold-storage room, the following four basic sources of heat flow into the room are considered: (1) wall-heat-gain load (q'_w), (2) air change or service load (q'_s), (3) product load (q'_p), and (4) miscellaneous load (q'_m). The total heat load is the sum of these four sources. Conventionally, this sum is increased by 10 percent to allow for a factor of safety.

In the first of the following subsections, the relationships between the various symbols representing heat (the quantity of heat and the rate of heat flow) are explained. In the remaining subsections, the four basic sources of heat flow are considered.

Relationships between Symbols Representing Quantity of Heat and Rate of Heat Flow

Symbols Employed

Inasmuch as the removal of heat is the basic problem treated in refrigeration, it is convenient to have symbols for the representation of heat. The following are the ones used in this leaflet:

Q	= quantity of heat,	in	B.t.u.	
q	= rate of heat flow,	in	$\frac{\text{B.t.u.}}{\text{hr.}}$	or B.t.u./hr.
q'	= rate of heat flow,	in	$\frac{\text{B.t.u.}}{24 \text{ hr.}}$	or B.t.u./24 hr.

If "t" represents the time, in hours, the relationships between the symbols are as follows:

$$\begin{aligned}
 q &= \frac{Q}{t} && \text{in } \frac{\text{B.t.u.}}{\text{hr.}} \\
 q' &= 24q \frac{\text{hr.}}{24 \text{ hr.}} && \text{in } \frac{\text{B.t.u.}}{\text{hr.}} \times \frac{\text{hr.}}{24 \text{ hr.}} = \frac{\text{B.t.u.}}{24 \text{ hr.}} \\
 &= 24 \frac{Q}{t} \frac{\text{hr.}}{24 \text{ hr.}} && \text{in } \frac{\text{B.t.u.}}{\text{hr.}} \times \frac{\text{hr.}}{24 \text{ hr.}} = \frac{\text{B.t.u.}}{24 \text{ hr.}}
 \end{aligned}$$

Example of Typical Use

The following example shows a typical use of these symbols:

if $Q = 32,000 \text{ B.t.u.}$ (quantity of heat removed from product) and
 $t = 16 \text{ hr.}$ (time needed to remove heat),

then $q = \frac{Q}{t} = \frac{32,000 \text{ B.t.u.}}{16 \text{ hr.}} = 2,000 \frac{\text{B.t.u.}}{\text{hr.}}$ and

$$\begin{aligned}
 q' &= 24q \frac{\text{hr.}}{24 \text{ hr.}} = 24(2,000 \frac{\text{B.t.u.}}{\text{hr.}}) \frac{\text{hr.}}{24 \text{ hr.}} = 48,000 \frac{\text{B.t.u.}}{24 \text{ hr.}} \quad \text{or} \\
 &= 24 \frac{Q}{t} \frac{\text{hr.}}{24 \text{ hr.}} = 24(\frac{32,000 \text{ B.t.u.}}{16 \text{ hr.}}) \frac{\text{hr.}}{24 \text{ hr.}} = 48,000 \frac{\text{B.t.u.}}{24 \text{ hr.}}
 \end{aligned}$$

In the discussions that follow, the details of these conversions will be omitted to save space.

Wall-Heat-Gain Load

Basic Heat-Flow Equation

The heat entering the cold-storage room through the walls, ceiling, and floor depends upon (1) the type and thickness of the insulation and of the other construction materials, (2) the outside surface area of the cold-storage room, and (3) the difference between the temperature of the air inside the cold-storage room and that of the air outside. These factors may be combined into a basic heat-flow equation:

$$q = \frac{kA}{x} (T_2 - T_1) \quad \text{where,}$$

q = rate of heat leakage into the cold region, in B.t.u. per hour.

A = surface area, in square feet (based on outside dimensions).

T_2 = temperature on the warm side (outside air temperature), in °F.

T_1 = temperature on the cold side (refrigerator air temperature, in °F.

x = thickness, in inches, of material bounding the cold region.

k = conductivity constant of material bounding cold region, in the units $\frac{2}{(\text{ft.}^2)(\text{°F./in.})} (\text{B.t.u./hr.})$

Conductivity Constant (k)

The significance of the conductivity constant k may be more readily understood from figure 14. This constant is defined as the rate of heat flow, in B.t.u. per hour, through a 1-square-foot surface of 1-inch thickness with a 1° F. temperature difference between the two sides of the surface.

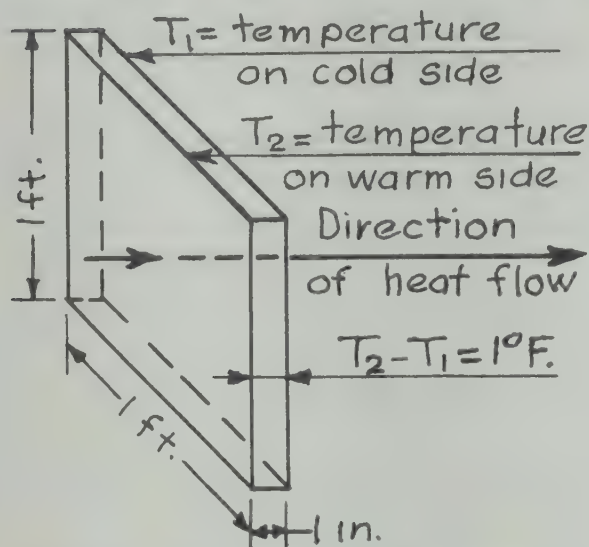


Figure 14.--Standard conditions for determination of conductivity constant.

If: $A = 1 \text{ sq. ft.}$
 $T_2 - T_1 = 1^\circ \text{ F.}$
 $x = 1 \text{ in.}$
 (time = 1 hr.)

Then: $q = \frac{kA}{x} (T_2 - T_1)$
 $= \frac{k(1)(1)}{(1)}, \quad \text{or}$

$q = k \text{ (numerically)}$

Data on k factors for some common industrial materials used for insulation and construction are listed in table 1. Such values are usually given in "per inch of thickness" and are expressed in the units:

$$\frac{(\text{B.t.u./hr.})}{(\text{ft.}^2)(\text{°F./in.})}$$

but occasionally they will be given in "per foot of thickness" and will be expressed in the units:

$$\frac{(\text{B.t.u./hr.})}{(\text{ft.}^2)(\text{°F./ft.})} \quad \text{or, simplifying} \quad \frac{(\text{B.t.u./hr.})}{(\text{ft.})(\text{°F.})}$$

To convert either of the latter two k values to the former one, multiply either of these values by 12.

2/ To those not accustomed to working with refrigeration, units such as this one may seem to be somewhat complex. The careful use of these units, however, clarifies the problems and aids in the avoidance of errors. The method of handling the units will be shown in the numerous illustrative problems that follow.

Table 1.—Thermal conductivities of some common insulating materials

Description	Density	Mean temp.	Conductivity coefficients	
			k	U
	<u>Lb. per ft.³</u>	<u>°F.</u>	<u>1/</u>	<u>2/</u>
Air space, 1-in. thick bounded by ordinary materials		60		1.07
		30		0.98
		0		0.89
Air space, 1-in. thick bounded on warm side by aluminum paint		60		0.62
		30		0.59
		0		0.57
Air space, 1-in. thick bounded on warm side by aluminum foil		60		0.46
		30		0.46
		0		0.45
Aluminum foil, crumpled	0.2		0.28	
Aluminum foil, spaced	2.4		0.22	
Asbestos, packed	43.8		1.52	
Asbestos, loose	29.3		0.94	
Asbestos, corrugated	16.2		0.52	
Asphalt	132	68	5.2	
Concrete	150		12.0	
Corkboard	7.07	0	0.27	
	7.07	-14	0.23	
	10.5		0.28	
Felt—wool	20.6	86	0.38	
Fiberglas	3.0		0.24	
Fir, Douglas, 0% moisture	34	75	0.67	
Glass wool	1.65	60	0.27	
	1.65	30	0.25	
	1.65	0	0.23	
Mineral wool	3.5	60	0.27	
	3.5	30	0.24	
	3.5	0	0.22	
Pine, Oregon	37.0		0.80	
Pine, white	31.2	86	0.78	
Pine, yellow			1.00	
Rock wool	6.0		0.26	
	10.0	90	0.27	
	18.0		0.29	
Rubber board, expanded	4.5	60	0.22	
	4.5	30	0.22	
	4.5	0	0.21	
Wood fiberboard, 3/4-in. thick (moisture as received)	17.0	72		0.33

$$\frac{1}{\frac{(\text{B.t.u./hr.})}{(\text{ft.}^2)(\text{°F./in.})}}$$

$$\frac{2}{\frac{(\text{B.t.u./hr.})}{(\text{ft.}^2)(\text{°F.})}}$$

Calculation for Single-Wall Construction

Calculation by use of basic heat-flow equation.—The following problem shows how to calculate the wall-heat-gain load by use of the basic heat-flow equation. In this problem, only the insulation material is considered. For walls made up of thick insulation, the small error that results from neglecting the other wall-construction materials is on the safe side.

Problem 1a

- Given:
1. 50 ft. x 50 ft. x 10 ft. outside dimensions of cold-storage room.
 2. 6 in. corkboard insulation (walls, ceiling, floor) of density 10.5 lb./ft.³
 3. 0° F. air temperature inside refrigerator.
 4. 95° F. air temperature outside refrigerator.

To find: The wall-heat-gain load in B.t.u./24 hr. (q'_w).

$$\begin{aligned}\text{Solution: } q &= \frac{kA}{x} (T_2 - T_1) & k &= 0.28 \frac{\text{(B.t.u./hr.)}}{(\text{ft.}^2)(^\circ\text{F./in.})} \\ &= \frac{(0.28)(7,000)(95)}{6} & & \text{(from table 1).} \\ &= 31,000 \text{ B.t.u./hr.} & A &= 50 \times 50 \times 2 + 50 \times 10 \times 4 \\ & & &= 7,000 \text{ ft.}^2 \\ q'_w &= (24)(31,000) & T_2 &= 95^\circ \text{ F.} \\ &= 744,000 \text{ B.t.u./24 hr.} & T_1 &= 0^\circ \text{ F.} \\ & & T_2 - T_1 &= 95^\circ \text{ F.} \\ & & x &= 6 \text{ in.}\end{aligned}$$

Calculation by use of table.—Instead of using the basic-heat-flow formula, the designer can estimate the wall-heat-gain load by using table 2. The heat leakages through different thicknesses of cork or cork-equivalent insulation are listed in table 2 for various temperature differences (outside temperature minus cold-storage-room temperature). The use of this table may be more readily understood by repeating the calculation for the conditions given in problem 1a:

Problem 1b

- Given:
1. Outside surface area = 7,000 ft.²
 2. Cork insulation = 6 in.
 3. Temperature difference = 95° F.

To find: The wall-heat-gain load in B.t.u./24 hr. (q'_w).

Table 2.--Wall-heat gain for various temperature differences and thicknesses of cork or equivalent insulation (based on thermal conductivity, $k = 0.30$) $\frac{1}{1}$

Insulation (cork or cork equivalent ₂ /)	Wall-heat gain for temperature differences (outside design, or ambient, temperature minus refrigerator temperature in °F.) of:																	
	1°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°
Inches																		
1	7.3	292	329	365	402	438	475	511	548	584	621	657	694	730	767	803	840	876
2	3.6	144	162	180	198	216	234	252	270	288	306	324	342	360	378	396	414	432
3	2.4	96	108	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288
4	1.8	72	81	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216
5	1.44	58	65	72	79	86	94	101	108	115	122	130	137	144	151	158	166	173
6	1.2	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144
7	1.03	41	46	52	57	62	67	72	77	82	88	93	98	103	108	113	118	124
8	.90	36	41	45	50	54	59	63	68	72	77	81	86	90	95	99	104	108
9	.80	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96
10	.72	29	32	36	40	43	47	50	54	58	61	65	68	72	76	79	83	86
11	.66	26	30	33	36	40	43	46	50	53	56	59	63	66	69	73	76	79
12	.60	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
13	0.55	22	25	28	30	33	36	39	41	44	47	50	52	55	58	61	63	66
14	0.51	20	23	26	28	31	33	36	38	41	43	46	49	51	54	56	59	61

$\frac{1}{1}$ Method of using values in table 2 to convert to wall-heat-gain load:

Table 2 value (B.t.u./24 hr./sq.ft.) x outside surface area of cold-storage room (sq. ft.) = total wall-heat-gain load (B.t.u./24 hr.).

$\frac{2}{2}$ The equivalent thickness of an insulation material in terms of cork is obtained by multiplying the ratio,

$\frac{\text{thermal conductivity of material}}{\text{thermal conductivity of cork}} = \frac{k_m}{k_c}$, by the thickness of cork in this table. Thus, the equivalent thickness of

expanded rubber board ($k = 0.21$; table 1) in terms of 6 inches of corkboard ($k = 0.28$; table 1) for 0° F. usage is:

$\frac{k_m}{k_c} \times 6 \text{ in.} = \frac{0.21}{0.28} \times 6 = 4.5 \text{ in.}$ The cork equivalents of a series of materials are additive.

Solution: For values of 6 in. and 95° F., enter table 2 and obtain

$$\frac{q'_w}{\text{ft.}^2} = \frac{114 \text{ (B.t.u.)}}{(24 \text{ hr.})(\text{ft.}^2)} \text{. This value can be converted to B.t.u./24 hr. by the following calculation:}$$

$$\begin{aligned} q'_w &= \frac{114 \text{ (B.t.u.)}}{(24 \text{ hr.})(\text{ft.}^2)} \times 7,000 \text{ ft.}^2 \\ &= 798,000 \text{ B.t.u./24 hr.}^3/ \end{aligned}$$

Calculation for Multiple-Wall Construction

Generally, insulated walls are made up of two or more materials; and the resistance to the flow of heat through the main insulating material is usually so much greater than that through the other materials that the flow of heat through these other materials may ordinarily be neglected, as was done in problems 1a and 1b. When, however, it is desirable to evaluate the additional insulating effect of the other materials, the basic heat-flow equation $q = \frac{kA}{x} (T_2 - T_1)$ must be modified. The term $\frac{k}{x}$ instead of representing a single material must now represent the series of materials being considered. This overall term is called the coefficient of transmittance or overall coefficient of heat transfer and is commonly designated by the symbol U.

The heat-flow equation for a multiple-wall material may thus be expressed in the form:

$$q = UA(T_2 - T_1) \quad \text{where,}$$

$$U = \frac{1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \dots}, \text{ in } \frac{\text{(B.t.u./hr.)}}{(\text{ft.}^2)(^\circ\text{F.})}$$

x = thickness of each layer of material, in in.

k = conductivity of each layer of material, in $\frac{\text{(B.t.u./hr.)}}{(\text{ft.}^2)(^\circ\text{F./in.})}$

q = rate of heat leakage into cold region, in B.t.u./hr.

A = surface area, in sq. ft. (based on outside dimensions).

T₂ = temperature on the warm side (outside air temperature), in °F.

T₁ = temperature on the cold side (refrigerator air temperature), in °F.

^{3/} This value (798,000) is slightly higher than that obtained in problem 1a (744,000), because table 2 is based upon a conductivity of k = 0.30. If a k value of 0.28 more accurately reflects the particular insulation used, 798,000 can be multiplied by 0.28/0.30 to obtain 745,000, which is in close agreement with 744,000.

Calculation neglecting air films.—The following problem shows how to calculate the wall-heat-gain load for a wall of multiple construction, neglecting air films:

Problem 2

- Given: 1. 50 ft. x 50 ft. x 10 ft. cold-storage room
 2. 0° F. inside temperature.
 3. 95° F. outside temperature.
 4. Wall construction as shown in figure 15.

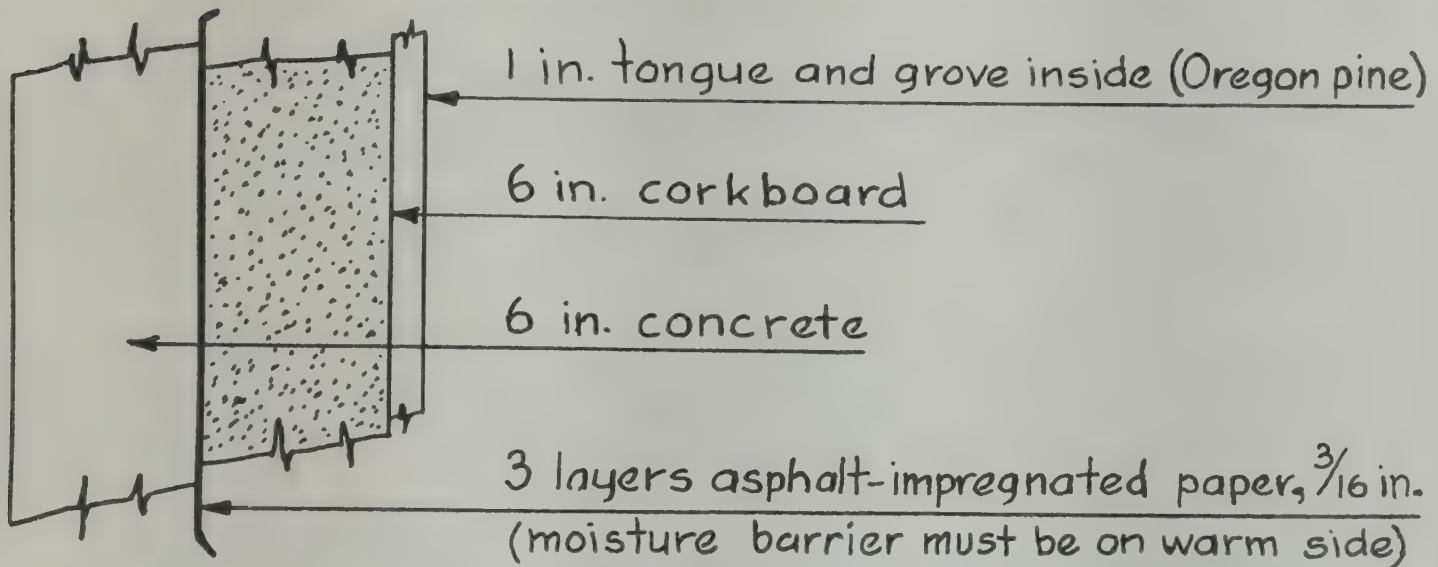


Figure 15.—Cross section of wall of cold-storage room.

To find: The wall-heat-gain load in B.t.u./24 hr. (q'_w).

$$\begin{aligned} \text{Solution: } U &= \frac{1}{\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{x_4}{k_4}} \\ &= \frac{1}{\frac{6}{12} + \frac{3/16}{5.2} + \frac{6}{0.28} + \frac{1}{0.80}} \\ &= \frac{1}{0.50 + 0.04 + 21.43 + 1.25} \\ &= \frac{1}{23.22} \\ &= 0.0431 \frac{\text{B.t.u./hr.}}{(\text{ft.}^2)(^\circ\text{F.})} \end{aligned}$$

$$\begin{aligned} q &= UA(T_2 - T_1) \\ &= (0.0431)(7,000)(95) \\ &= 28,700 \text{ B.t.u./hr.} \end{aligned}$$

$$\begin{aligned} q'_w &= 24 \times 28,700 \\ &= 689,000 \text{ B.t.u./24 hr.} \end{aligned}$$

$$\begin{aligned} k_1 &= 12 \frac{\text{B.t.u./hr.}}{(\text{ft.}^2)(^\circ\text{F./in.})} \\ k_2 &= 5.2 \text{ " } \\ k_3 &= 0.28 \text{ " } \\ k_4 &= 0.80 \text{ " } \\ &\text{(all from table 1).} \end{aligned}$$

$$\begin{aligned} x_1 &= 6 \text{ in.} \\ x_2 &= 3/16 \text{ in.} \\ x_3 &= 6 \text{ in.} \\ x_4 &= 1 \text{ in.} \end{aligned}$$

$$A = 7,000 \text{ sq. ft. (from problem 1).}$$

$$T_2 - T_1 = 95^\circ \text{ F.}$$

The calculated wall-heat-gain load in problem 2 is 7.4 percent less than that in problems 1a and 1b, owing to the insulating effect in problem 2 of the concrete, asphalt vapor barrier, and Oregon pine. For small installations, such as this one, it is common practice in the calculation of the wall-heat-gain load to ignore the effect of the building materials other than the insulation. This practice provides an extra factor of safety. For large installations, however, the insulating effect of all the building materials must be considered because of the large surface area involved. Failure to include the insulating effect of these other materials would result in the purchase of unnecessary refrigeration equipment.

The insulating effect of air films has been neglected in problem 2 because this effect is usually insignificant in the case of small installations with well-insulated walls. If, however, the effects of air films are to be included in the calculation, as in that for a large cold storage, the symbol U in the basic heat flow equation $q = UA(T_2 - T_1)$ takes the form:

$$U = \frac{1}{\frac{1}{f_0} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \dots + \frac{1}{f_1}} \quad \text{where,}$$

x = thickness of each layer of material in in.

k = thermal conductivity of each layer of material.

f_0 = factor for outside air film = 6.5. This value of 6.5 is for an outside surface exposed to the weather and is the estimated insulation effect of a surface air film with a 15-mile-per-hour wind blowing. If this outside surface is on a refrigerator located inside of a building or in an otherwise protected location where the wind does not blow upon it, then $f_0 = 1.65$.

f_1 = factor for inside air film = 1.65. This value is for still air and is the estimated insulation effect of the stationary air film that clings to the surface.

Calculation including air films.—The following problem shows how to include the effects of air films in calculating the wall-heat-gain load for a wall of multiple construction:

Problem 3

Given: The same data as those in problem 2 except that the air films on the outside and inside walls are included.

To find: The wall-heat-gain load in B.t.u./24 hr. (q').

$$\begin{aligned}
 \text{Solution: } U &= \frac{1}{\frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{x_4}{k_4} + \frac{1}{f_i}} \\
 &= \frac{1}{\frac{1}{6.5} + 0.50 + 0.04 + 21.43 + 1.25 + \frac{1}{1.65}} \\
 &= \frac{1}{23.98} \\
 &= 0.0417 \frac{\text{B.t.u./hr.}}{(\text{ft.}^2)(^\circ\text{F.})}
 \end{aligned}$$

$$\begin{aligned}
 q &= (0.0417)(7,000)(95) \\
 &= 27,700 \text{ B.t.u./hr.}
 \end{aligned}$$

$$\begin{aligned}
 q_w' &= 24 \times 27,700 \\
 &= 665,000 \text{ B.t.u./24 hr.}
 \end{aligned}$$

The calculated wall-heat-gain load in problem 3 is 10.6 percent less than that in problems 1a and 1b, owing to the insulating effect of the construction materials plus the air films on the outside and inside walls.

Inasmuch as the wall-heat-gain is only one part of the total heat load, it is customary to omit the insulating effect of the air films and of the materials other than the main insulation, especially if the installation is a small one with insulated walls of the recommended thickness.

Thickness of Insulation

To determine the proper thickness of insulation, the designer must consider such factors as the type of insulation and its cost, the type of construction, the temperature differentials, and the operating costs of the refrigeration equipment. There is an optimum point where the fixed charges for insulation, construction, and equipment are in approximate balance with operating costs, and the total costs are close to a minimum.

Economical thicknesses have been worked out for the range of temperature differentials commonly encountered. A list of these economical thicknesses is given in table 3. It is not always practical, however, to employ the recommended thickness. Domestic freezer boxes, for example, must be able to go through a 2-foot 8-inch door; and commercial boxes, through a 3-foot door. To install the recommended insulation thickness in such boxes would make the usable space too small. A compromise must therefore be made between the standard of insulation and the limitations of space. Some of the newer synthetic insulations with low k factors are helping to meet these needs.

Table 3.--Recommended minimum thicknesses of insulation for refrigerators located in the northern or southern part of the United States, based on standards of the refrigeration industry

Temperature of refrigerator	Cork or equivalent thickness ^{1/}	
	In northern U. S.	In southern U. S.
<u>°F.</u>	<u>Inches</u>	<u>Inches</u>
50 to 60	2	3
40 to 50	3	4
25 to 40	4	5
15 to 25	5	6
0 to 15	6	7
-15 to 0	7	8
-40 to -15	9	10

^{1/} Method of calculating cork-equivalent thickness is given in footnote 2 of table 2.

The choice of insulation thickness is sometimes closely related to the fabrication costs or to the special conditions of installation. For example, in insulating the hold of a small boat equipped with steel tanks, stiffened with 2-inch angles, for holding sea water at 30° F., the maximum insulation would probably be 2 inch (standard calls for 4 inch; table 3). To go to a thicker insulation, however, might unduly increase the fabrication costs. Furthermore, since by far the largest portion of the refrigeration costs go into precooling the sea water and cooling the incoming fish and since this type of installation is operated only during a small fraction of the year, it would be advisable to keep fixed capital costs of insulation to a minimum.

Outside Design Temperature

The "outside design temperature" is the basic temperature from which heat loads are calculated. It is defined as the temperature, in the locality of the refrigerator, that is not exceeded more than a given percentage of the time. An average temperature is not used because on the hottest days--when the refrigeration is most needed--the equipment would be too small. On the other hand, the maximum recorded temperature is not used because the total effect of this higher-than-design temperature does not manifest itself immediately. Thus, before this higher temperature begins seriously to affect the load on the refrigeration equipment, it ordinarily begins to drop off, owing to a change in conditions, such as the setting of the sun. Inasmuch as the equipment is selected with an adequate factor of safety, it is reasonable to work on the basis of

less than the worst temperature conditions.

Determination of outside design temperature.—Outside design temperatures for a given locality can be determined from data obtained from the local United States Weather Bureau office, from the local newspaper office, or from some standard reference such as the American Society of Refrigerating Engineers Data Book, Design Volume.

Corrections to outside design temperature.—If the refrigerator is exposed to direct sunlight, additional heat must be added to the heat load. This correction can conveniently be made by adding to the design temperature the proper values found in table 4 for the walls and roof. The design temperature for floors that are set directly on the ground without a ventilation space underneath should be lowered by 20° F. (the ground temperature is considered to be 20° F. below the outside air temperature).

Table 4.—Correction to outside design temperature for solar radiation

Type of surface	Amount ^{1/} to be added to design temperature for:			
	East wall	South wall	West wall	Flat roof
	<u>°F.</u>	<u>°F.</u>	<u>°F.</u>	<u>°F.</u>
Dark-colored surfaces, such as slate roofing, tar roofing, and black paints	8	5	8	20
Medium-colored surfaces, such as unpainted wood, brick, red tile, dark cement, and paints (red, gray, green)	6	4	6	15
Light-colored surfaces, such as white stone, light-colored cement, and white paint	4	2	4	9

^{1/} These values are applicable for the full 24-hour day.

If walls are common with other storage areas, the design temperature should be appropriately modified.

Air Change or Service Load

The air change or service load accounts for the flow of heat into the refrigerator caused by door openings and other similar leakages. The effect of door openings and other leakage sources is difficult to estimate accurately;

a number of different methods of estimation have consequently been developed.

Service Load Estimated on Basis of Wall-Heat-Gain Load

(1) A common method used by some designers is to estimate the air change or service load as 15 percent of the wall-heat-gain load. Under some conditions, this estimate will be too low.

(2) Other designers use an estimate of 20 percent for light service, 33-1/3 percent for normal or average service, and 50 percent for heavy service.

Service Load Estimated on Basis of Volume of Refrigerator

Still other designers reason that the number of door openings and resulting air changes is related to the volume of the refrigerator. Data on air changes per 24 hours due to door openings and air infiltration are given in table 5. Experience has shown that this table is practical.

Table 5. Data for estimation of air change or service load: average air changes per 24 hours due to door openings and air infiltration for cold-storage rooms of various volumes

Net volume of room	Average air changes per 24 hr.	Net volume of room	Average air changes per 24 hr.	Net volume of room	Average air changes per 24 hr.
<u>Cubic feet</u>	<u>Number</u>	<u>Cubic feet</u>	<u>Number</u>	<u>Cubic feet</u>	<u>Number</u>
200	44.0	2,000	12.0	20,000	3.5
300	34.5	3,000	9.5	25,000	3.0
400	29.5	4,000	8.2	30,000	2.7
500	26.0	5,000	7.2	40,000	2.3
600	23.0	6,000	6.5	50,000	2.0
800	20.0	8,000	5.5	75,000	1.6
1,000	17.5	10,000	4.9	100,000	1.4
1,500	14.0	15,000	3.9		

1/ For heavy usage, multiply these values by 2. For light usage or long storage, multiply the values by 0.6.

The heat given up to the refrigerator for each cubic foot of air taken from outside conditions to refrigerator conditions is given in table 6.

The air change or service load in B.t.u./24 hr. (q'_s) is calculated from tables 5 and 6 by use of the equation:

$$q'_s = VNQ_{cft}$$

where,

V = volume of air per air change (usually taken as the inside volume of the refrigerator), in ft.³/air change.

N = number of air changes per 24 hours, in air changes/24 hr.

Q_{cft} = heat extracted in cooling outside air to temperature of the refrigerator, in B.t.u./ft.³

Table 6.--Data^{1/} for estimation of air change or service load: heat given up by outside air in cooling to cold-storage temperatures

Temperature of cold-storage room		Heat given up by outside air at temperatures and relative humidities of:							
		85° F.		90° F.		95° F.		100° F.	
		50%	60%	50%	60%	50%	60%	50%	60%
°F.	B.t.u. per cu. ft.								
50	1.32	1.54	1.62	1.87	1.93	2.22	2.28	2.65	
45	1.50	1.73	1.80	2.06	2.12	2.42	2.47	2.85	
40	1.69	1.92	2.00	2.26	2.31	2.62	2.67	3.06	
35	1.86	2.09	2.17	2.43	2.49	2.79	2.85	3.24	
30	2.00	2.24	2.26	2.53	2.64	2.94	2.95	3.35	
		40° F.		50° F.		90° F.		100° F.	
		70%	80%	70%	80%	50%	60%	50%	60%
		B.t.u. per cu. ft.							
30	0.24	0.29	0.58	0.66	2.26	2.53	2.95	3.35	
25	0.41	0.45	0.75	0.83	2.44	2.71	3.14	3.54	
20	0.56	0.61	0.91	0.99	2.62	2.90	3.33	3.73	
15	0.71	0.75	1.06	1.14	2.80	3.07	3.51	3.92	
10	0.85	0.89	1.19	1.27	2.93	3.20	3.64	4.04	
5	0.98	1.03	1.34	1.42	3.12	3.40	3.84	4.27	
0	1.12	1.17	1.48	1.56	3.28	3.56	4.01	4.43	
- 5	1.23	1.28	1.59	1.67	3.41	3.69	4.15	4.57	
-10	1.35	1.41	1.73	1.81	3.56	3.85	4.31	4.74	
-15	1.50	1.53	1.85	1.92	3.67	3.96	4.42	4.86	
-20	1.63	1.68	2.01	2.09	3.88	4.18	4.66	5.10	
-25	1.77	1.80	2.12	2.21	4.00	4.30	4.78	5.21	
-30	1.90	1.95	2.29	2.38	4.21	4.51	4.90	5.44	

^{1/} These data are used in conjunction with those in table 5.

The following problem illustrates how tables 5 and 6 and this equation are employed:

Problem 4

- Given: 1. 50 ft. x 50 ft. x 10 ft. cold-storage room.
2. 6 in. cork insulation; 12 in. overall wall thickness.
3. 90° F. outside temperature.
4. 60% relative humidity.
5. 0° F. temperature of cold-storage room.
6. 1 door in room.

To find: Service load in B.t.u./24 hr. (q'_s).

Solution: $V = 48 \times 48 \times 8$
 $= 18,400 \text{ ft.}^3$

$N = 3.63$ air changes per 24 hr. (obtained from table 5 by interpolating for 18,400 ft.³).

$Q_{\text{cft}} = 3.56 \text{ B.t.u./ft.}^3$ (obtained from table 6 for heat extracted per ft.³ to cool air from 90° F. and 60% relative humidity to 0° F.).

$q'_s = VNQ_{\text{cft}}$
 $= (18,400)(3.63)(3.56)$
 $= 238,000 \text{ B.t.u./24 hr.}$

Product Load

A product placed in a cold storage at a temperature above that of the storage will give up heat until it reaches the storage temperature. The amount of heat given up by the product can be calculated from (1) the weight of product, (2) the initial temperature, (3) the specific heat of product above freezing, (4) the freezing temperature of the product, (5) the latent heat of the product, (6) the specific heat of the product below freezing, and (7) the final temperature.

Formulae for Calculation

Quantity of heat removed (Q).—When a given weight of product is cooled from one temperature to a lower one, some or all of the calculations outlined below must be made:

- (a) In cooling the product from the initial temperature (T_1) to a lower temperature (T_2) above freezing, such as in a chill room, the heat removed in B.t.u. (Q_{12}) is given by the formula:

$$Q_{12} = Wc(T_1 - T_2)$$

- (b) In cooling the product from the lower temperature (T_2) above freezing to the freezing temperature (T_f)^{4/}, the heat removed

^{4/} For calculation purposes, the freezing point of fishery products is usually assumed to be 28° F.

in B.t.u. (Q_{2f}) is given by the formula:

$$Q_{2f} = Wc(T_2 - T_f)$$

- (c) In freezing the product at the freezing temperature (T_f), the heat removed in B.t.u. (Q_f) is given by the formula:

$$Q_f = WL$$

- (d) In cooling the product from the freezing temperature (T_f) to the storage temperature (T_3), the heat removed in B.t.u. (Q_{f3}) is given by the formula:

$$Q_{f3} = Wc_i(T_f - T_3)$$

- (e) In cooling the product from the initial temperature (T_1) directly to the storage temperature (T_3), the total heat removed in B.t.u. (Q) is given by the formula:

$$Q = Q_{12} + Q_{2f} + Q_f + Q_{f3} = W[c(T_1 - T_f) + L + c_i(T_f - T_3)]$$

where,

W = weight of product, in pounds.

c = specific heat of fishery product above freezing, in B.t.u./(lb.)(°F.)

c_i = specific heat of fishery product below freezing, in B.t.u./(lb.)(°F.)

L = latent heat of fusion of fishery product, in B.t.u./lb.

Product load (q_p^*).—To convert the total amount of heat (Q) removed in the time " t " to the product load (q_p^*), divide " Q " by " t " and multiply by 24, as was shown in "Relationship Between Symbols Representing Quantity of Heat and Rate of Heat Flow."

Sample calculation.—The following problem shows how to determine the quantity of heat removed (Q) and the product load (q_p^*).

Problem 5a

- Given: 1. One ton of fish at 50° F. to be frozen to 0° F. every 24 hours by (a) prechilling to 40° F. in a chill room and (b) then freezing on shelf plates at -10° F.
2. $c = 0.8$; $c_i = 0.4$; and $L = 115$.

- To find: (1) The quantity of heat removed, in B.t.u. (Q).
(2) The product load in B.t.u./24 hr. (q_p^*).

Solution: To cool from 50° F. to 40° F. in chill room:

$$\begin{aligned}Q_{12} &= Wc(T_1 - T_2) \\&= (2,000)(0.8)(50-40) \\&= 16,000 \text{ B.t.u.}\end{aligned}$$

To cool from 40° F. to freezing temperature:

$$\begin{aligned}Q_{2f} &= Wc(T_2 - T_f) \\&= (2,000)(0.8)(40-28) \\&= 19,200 \text{ B.t.u.}\end{aligned}$$

To freeze at 28° F.:

$$\begin{aligned}Q_f &= WL \\&= (2,000)(115) \\&= 230,000 \text{ B.t.u.}\end{aligned}$$

To cool from freezing point to storage temperature:

$$\begin{aligned}Q_{f3} &= Wc_i(T_f - T_3) \\&= (2,000)(0.4)(28-0) \\&= 22,400 \text{ B.t.u.}\end{aligned}$$

To cool from 50° F. to 0° F. (total):

$$\begin{aligned}Q &= Q_{12} + Q_{2f} + Q_f + Q_{f3} \\&= 16,000 + 19,200 + 230,000 + 22,400 \\&= 288,000 \text{ B.t.u.}\end{aligned}$$

To convert to a B.t.u./hr. basis:

$$\begin{aligned}q &= \frac{Q}{t} \\&= \frac{288,000 \text{ B.t.u.}}{24 \text{ hr.}}\end{aligned}$$

To convert to a B.t.u./24 hr. basis:

$$\begin{aligned}q_p &= \frac{24(288,000) \text{ B.t.u.}}{\left(\frac{24}{24}\right) 24 \text{ hr.}} \\&= 288,000 \frac{\text{B.t.u.}}{24 \text{ hr.}}\end{aligned}$$

Specific Heats and Latent Heat of Fusion

The specific heats and the latent heat of fusion of a fishery product

depends, among other factors, upon the relative amounts of moisture, oil, and solids in the product and are difficult to determine precisely. For most fishery products, however, the following approximations will be found satisfactory:

c = specific heat above freezing = 0.8 B.t.u./ $(lb.)(^{\circ}F.)$

c_i = specific heat below freezing = 0.4 B.t.u./ $(lb.)(^{\circ}F.)$

L = latent heat of fusion = 115 B.t.u./lb.

The latent heat of fusion, in problem 5a, constitutes about 80 percent of the total product load $\frac{(230,000 \times 100)}{288,000}$. In product freezing calculations, such as this one, the latent heat of fusion will always constitute a high percentage of the product load.

Rate of Cooling or of Freezing

If problem 5a had been such that 1 ton of fish at 50° F. was to be frozen to 0° F. every 16 hours instead of every 24 hours, the calculations for the product load (q_p') would have been as follows:

Problem 5b

Given: One ton of fish at 50° F. to be frozen to 0° F. every 16 hours by (a) prechilling to 40° F. in a chill room and (b) then freezing on shelf plates at -10° F.

To find: Product load in B.t.u./24 hr. (q_p').

Solution: Q = 288,000 B.t.u. (the same as in problem 5a).
 t = 16 hr.

$$q = \frac{Q}{t} = \frac{288,000 \text{ B.t.u.}}{16} = 18,000 \text{ B.t.u./hr.}$$

$$q_p' = 24 \left(\frac{288,000}{16} \right) = 432,000 \text{ B.t.u./24 hr.}$$

Note that the product load in problem 5b is 50 percent larger than that in problem 5a. Thus close estimation of "t," the time required to cool or to freeze the product load, is essential.

The time "t" is determined by many factors—such as thickness of the product, type and thickness of the packaging material, freezing temperature employed, and method of freezing. In this connection, it is important to note that the freezing time is not necessarily decreased by an increase

in refrigerator capacity. (This subject is discussed further in section 3.)

Miscellaneous Load

All of the energy dissipated in the refrigerator must be included in the heat load. This energy comes originally from electric motors, electric lights, and men working in the area.

Electric Motors

Heat-load equivalent.—The useful energy output of the motor (h.p. rating) and the motor losses (friction and resistance) are given in table 7.

Table 7.—Heat equivalent of electric motors ^{1/}
under various conditions

Motor size	Heat equivalent under conditions of:		
	1	2	3
	Load inside refrigerator box and motor outside ^{2/}	Motor inside refrigerator box and load outside ^{3/}	Motor and load inside refrigerator box ^{4/}
<u>H.p.</u>	<u>B.t.u./hr./h.p.</u>	<u>B.t.u./hr./h.p.</u>	<u>B.t.u./hr./h.p.</u>
1/8 to 1/2	2545	1700	4250
1/2 to 3	2545	1150	3700
3 to 20	2545	400	2950

^{1/} The heat equivalent of electric motors is made up of two components: column 1, the useful horsepower output of the motor, and column 2, the frictional and electrical losses of the motor. Column 3 is the sum of these two components.

^{2/} Use values in column 1 if the driving motor is outside the refrigerator and the load is inside the box: for example, if a pump motor outside the box is circulating brine or chilled water within the box.

^{3/} Use values in column 2 if the driving motor is inside the refrigerator box and the load is outside the box: for example, if a motor within the box is driving a pump or fan outside the box or in another space.

^{4/} Use values in column 3 if the driving motor and its load are in the refrigerator box: for example, if a motor is driving the fan of a forced-circulation unit cooler.

Sample calculation.—The following example shows how to calculate the heat load due to a combination electric motor and fan located in the refrigerated storage area.

Problem 6a

Given: 1/3 h.p. motor driving fan for forced circulation of air through a unit cooler.

To find: Heat load in B.t.u./24 hr. (q'_{em}) due to motor and fan in refrigerated area.

Solution: 1 h.p. = 4,250 B.t.u./hr. (from table 7)
1/3 h.p. = 1,417 B.t.u./hr.

$$\begin{aligned} q'_{em} &= (1,417)(24) \\ &= 34,000 \text{ B.t.u./24 hr.} \end{aligned}$$

Electric Lights

Heat-load equivalent.—1 watt = 3.42 B.t.u./hr.

Sample calculation.—The following example shows how to calculate the heat load due to electric lights:

Problem 6b

Given: Two 100-watt lights in use from 8:00 a.m. to 4:00 p.m. in a cold-storage room.

To find: Heat load in B.t.u./24 hr. (q'_{el}) due to lights.

Solution: 1 watt = 3.42 B.t.u./hr.
200 watts = 200 x 3.42 = 684 B.t.u./hr.

$$\begin{aligned} q'_{el} &= (684)(24) \\ &= 16,400 \text{ B.t.u./24 hr.} \end{aligned}$$

Occupancy by People

Heat-load equivalent.—Table 8 gives the average hourly load due to occupancy at different temperatures of the cold-storage room. At best, however, this source of heat load is difficult to estimate accurately. People give up heat at varying rates, depending on the temperature of the working area, the type of clothing worn, the size of man, and the exertion put forth in doing the work. People going into the refrigerated area for short duration carry with them heat substantially above that given in table 8. If traffic of this type is heavy, additional allowances must therefore be made.

Table 8.—Heat equivalent per person working in cold-storage room

Temperature of cold-storage room	Heat equivalent ^{1/}
°F.	<u>B.t.u. per hr. per person</u>
50	720
40	840
30	950
20	1,050
10	1,200
0	1,300
-10	1,400

^{1/} These values are applicable for the full 24-hour day.

Sample calculation.—The following example shows how to calculate the heat load due to men working in the refrigerator.

Problem 6c

Given: Two men are stacking a 0° F. storage area with fish for 6 hours per day.

To find: Occupancy load in B.t.u./24 hr. (q_o') for the two men.

Solution: For one man working at 0° F.:

$$q = 1,300 \text{ B.t.u./hr. (from table 8)}$$

For two men working at 0° F.:

$$\begin{aligned} q &= 2 \times 1,300 \\ &= 2,600 \text{ B.t.u./hr.} \end{aligned}$$

$$\begin{aligned} q_o' &= (24)(2,600) \\ &= 62,000 \text{ B.t.u./24 hr.} \end{aligned}$$

Note that if the men worked more than 6 hours—say 16 or 20 hours—the occupancy load would still be the same because the rate of 1,300 B.t.u. per hour given in table 8 is figured for the full 24-hour day. Although in the above problem the load lasts for only 6 hours, sufficient refrigeration capacity must be provided for the full 24 hours to handle this maximum demand even though it means having a surplus of refrigeration capacity during the period when there is no heat load due to occupancy. This same principle applies in calculating the heat load for lights and motors in the cold-storage area.

Total Miscellaneous Load

The total miscellaneous load is equal to the sum of the loads due to electric motors, electric lights, and men working in the area:

$$q'_m = q'_{em} + q'_{el} + q'_o$$

Total Heat Load

Method of Calculation

The total heat load (q') is calculated as the sum of the four basic sources of heat flow plus 10 percent (for a safety factor):

$$q = 1.10(q'_w + q'_s + q'_p + q'_m)$$

With hypothetical data being assumed for each of the four basic sources of heat flow, the example given in table 9 illustrates how the total heat load can be calculated (hypothetical data for a freezer room are included to show how such data compare with those for a cold-storage room).

Table 9.—Calculation of total heat load

Heat load	Hypothetical cold-storage-room calculation data	Hypothetical freezing-room calculation data
	<u>B.t.u./24 hr.</u>	<u>B.t.u./24 hr.</u>
(1) Wall-heat-gain load	170,000	44,000
(2) Air-change or service load	101,000	21,000
(3) Product load	52,000	255,000
(4) Miscellaneous load	67,000	67,000
Sum	400,000	407,000
Ten percent factor of safety	40,000	41,000
Calculated total heat load	440,000	448,000

Note that, in cold-storage rooms, the product load is but a small part of the total heat load, whereas in freezing rooms, the product load is the principal part of the total heat load.

Rule-of-Thumb Methods

There are numerous short rule-of-thumb methods for estimating the total heat load. Some are based, fallaciously, only on the outside surface area of the refrigerator. The more acceptable methods, however, are

based on a combination of the surface area and the net volume.

In the latter procedure, the four heat-source loads (wall-heat-gain, air-change, product, and miscellaneous) are estimated as follows: (1) the wall-heat-gain load is evaluated in terms of the outside surface area of the refrigerator (table 2), and (2) the remaining three heat-gain loads are combined in an estimate based on the net volume of the refrigerator. Simplified tables for making this latter estimate are available in manufacturers' catalogues and in the American Society of Refrigerating Engineers Design Data Book. Although the data in these tables are based upon experience, they apply only under prescribed conditions. Consequently, use of these tables without a knowledge of the basic assumptions and limitations can lead to a very poor estimate. It is therefore suggested that these shortcut methods be relied upon only by the experienced estimator.

For freezing fishery products, one can obtain a very rough approximation of the required refrigeration capacity by (1) calculating the product load and (2) then adding additional capacity to take care of the other three sources of heat gain. The product load required to lower the temperature of 1 ton of fish from 50° to 0° in 24 hours is about 1 ton of refrigeration. The additional capacity added for the other three sources of heat gain depends upon the type of freezer used and has been variously estimated. The American Society of Refrigerating Engineers Applications Data Book gives a range of 25 to 100 percent for this additional capacity.

HOW TO CALCULATE THE SIZE OF THE COMPRESSOR

Method of Rating Compressors

The capacity of a refrigerating compressor is generally rated in B.t.u. per hour or in tons of refrigeration^{5/} at the desired evaporative temperature^{6/}. Small compressors used on domestic or commercial refrigerators may be rated (1) in B.t.u. per hour or (2) by the horsepower of

5/ This term is frequently abbreviated, and the rate of refrigerating effect is stated simply in tons. The standard commercial ton of refrigeration is arbitrarily defined as the removal of heat energy from the cold region at the rate of 288,000 B.t.u. per 24 hours or of 12,000 B.t.u. per hour. This unit derives from the fact that the latent heat of fusion of ice is approximately 144 B.t.u. per pound; thus, for a 24-hour period, 144 B.t.u. per pound x 2,000 pounds per ton equals 288,000 B.t.u. per 24 hours per ton. A refrigerating machine that is operating at a capacity of 1 ton is therefore absorbing heat energy at the same rate as 1 ton of ice would if it were melting in a 24-hour period.

6/ The evaporative temperature is the temperature of the refrigerant inside the evaporator.

the motor required to drive them. Large commercial or small industrial compressors may be rated (1) in tons of refrigeration, (2) in B.t.u. per hour, or (3) by the horsepower required to drive the unit. The ratings of B.t.u. per hour and tons of refrigeration, however, are the ones most commonly used in refrigeration terminology.

Method of Determining Required Size of Compressor

The selection of the proper size of compressor involves the consideration of five factors:

1. The calculated total heat load.
2. The actual hours of operation of the compressor.
3. The calculated capacity of the compressor.
4. The temperature of the refrigerant in the evaporator (evaporative temperature).
5. The available sizes of compressors.

Calculated Total Heat Load (q')

The calculated total heat load in B.t.u. per 24 hours (q') is used as the basis for determining the compressor capacity in B.t.u. per hour or in tons of refrigeration. The method of using q' to determine the compressor capacity is illustrated in problem 7.

Hours of Operation of Compressor (t_c)

If it were possible to operate a compressor 24 hours per day, the calculated total heat load in B.t.u. per 24 hours (q') could be expressed directly as the required compressor capacity (after conversion to B.t.u. per hour). Thus, a calculated total heat load (q') of 240,000 B.t.u. per 24 hours would require a compressor capacity of 10,000 B.t.u. per hour. Compressors, however, are usually not operated continuously for 24 hours per day, as is assumed in the calculation of the total heat load. Rather, they are operated noncontinuously in order to obtain a maximum of trouble-free service, to allow for a defrost cycle, and to provide for normal maintenance and repair. Conventionally, 16 hours of operation of the compressor per 24 hours is considered good practice, but other operating times are used. The most common of these are listed in the following:

No defrost cycle.--If the refrigerant temperature is above 30° F., ice will not form on the coils. Under these conditions, general practice favors basing the size of the equipment on an operating time of 18 or 20 hours.

Natural defrost cycle.--If a natural defrost cycle using the heat from the refrigerator air at 35° F. and above is employed, general practice favors basing the size of the equipment on an operating time of 16 hours.

Artificial defrost cycle.---Artificial defrost cycles are of two kinds: (1) automatic and (2) manual.

If an automatic defrost cycle is employed (refrigerator temperatures below 35° F.), the amount of heat added during defrosting depends on the method of operation. The manufacturer therefore ordinarily furnishes data on the heat gain due to defrosting and recommends the operating time to be used in calculations. In the absence of specific data from the manufacturer, an operating time of 16 hours can be assumed safely.

If a manual defrost cycle is employed (the defrosting is ordinarily done once a year), the operation is equivalent to no defrost because the time of defrosting can be chosen when the refrigeration load is the lightest. At such a time, the reserve refrigeration capacity is ample. An operating time of 18 or 20 hours (the same as that employed with no defrost) is therefore used.

Calculated Capacity of Compressor (q_c or q_{ct})

To correct for this less-than-24-hour-per-day operation of the compressor, the required compressor capacity (q_c in B.t.u. per hour, or q_{ct} in ton of refrigeration) is determined as follows:

$$q_c = \frac{q'}{t_c} \quad \text{or} \quad q_{ct} = \frac{q_c}{(12,000 \text{ B.t.u./hr.}) / (\text{ton of refrigeration})}$$

where, q' is the total heat load in B.t.u. per 24 hours and t_c is the actual time of operation of the compressor per 24 hours.

The following problem shows how the required size of the compressor is calculated:

Problem 7

- Given:
1. 480,000 B.t.u./24 hr., calculated total heat load, q' .
 2. 16 hr., time (t_c) of compressor operation per 24-hr. day.
 3. 0° F., temperature of cold-storage space.
 4. -10° F., evaporative temperature (specified when compressor is ordered, but does not otherwise enter into the calculation).

To find: The capacity or size of the required compressor (1) in B.t.u./hr. (q_c) and (2) in ton of refrigeration (q_{ct}).

Solution: (1) B.t.u.-per-hour basis

$$q_c = \frac{480,000 \text{ B.t.u./24 hr.}}{16 \text{ hr./24 hr.}}$$

= 30,000 B.t.u./hr. at an evaporative temperature of -10° F. (basis for selection of compressor).

(2) Ton-of-refrigeration basis

As previously defined, 1 ton of refrigeration equals 288,000 B.t.u. per 24 hours or 12,000 B.t.u. per hour.

Therefore,

$$\begin{aligned} q_{ct} &= \frac{q_c}{(12,000 \text{ B.t.u./hr.})/(\text{ton of refrigeration})} \\ &= \frac{(30,000 \text{ B.t.u./hr.})}{(12,000 \text{ B.t.u./hr.})/(\text{ton of refrigeration})} \\ &= 2.5 \text{ ton of refrigeration at an evaporative} \\ &\quad \text{temperature of } -10^\circ \text{ F. (basis for selection} \\ &\quad \text{of compressor)} \checkmark. \end{aligned}$$

Evaporative Temperature

Inasmuch as the output of the compressor depends upon the evaporative temperature, this temperature must be specified to the compressor manufacturer to assure that the selected equipment will be of a suitable size. The evaporative temperature, however, does not otherwise enter into the calculations for determining the desired size of the compressor.

(It should be pointed out that general practice favors a difference of not more than 10° F. between the temperature of the refrigerant in the evaporator and that of the refrigerated storage space in order to prevent dessication of the product.)

Selection of Compressor Size

The size of the compressor is selected on the basis of the calculated capacity requirements (at the evaporative temperature) in B.t.u. per hour (q_c) or in tons of refrigeration (q_{ct}) as was illustrated in problem 7. Inasmuch as compressors are manufactured in standard sizes, probably none of them will be exactly equal to the size indicated by the calculations. The next larger available size rather than the next smaller size should be the one chosen and is symbolically represented by q_c^* or q_{ct}^* . (Other considerations in the selection of a compressor are given in section 2.)

\checkmark An alternate way of making this calculation would be:

$$\begin{aligned} q_{ct} &= \frac{480,000 \text{ B.t.u./24 hr.}}{(288,000 \text{ B.t.u./24 hr.})/(\text{ton of refrigeration})} \times \frac{1}{16 \text{ hr./24 hr.}} \\ &= (1.67 \text{ ton refrigeration}) \times \frac{24}{16} = 2.50 \text{ ton of refrigeration at an} \\ &\quad \text{evaporative temperature of } -10^\circ \text{ F.} \end{aligned}$$

HOW TO CALCULATE THE SIZE OF THE EVAPORATOR

Formula for Calculation

Heat required for evaporation of the refrigerant is supplied to the evaporator surface by the surrounding medium that is being cooled. This medium might be a gas, such as the air in the refrigerator; a liquid, such as brine; or a solid, such as a fish product. The rates of heat flow into the evaporator are controlled by a number of factors, which include the type of evaporator (bare pipe or tubing, finned pipe coils, or refrigerated plates), the material and type of construction of the evaporator, the exposed area of the evaporator, and the temperature difference between the surrounding medium and the refrigerant. The same principles employed in the calculation of the flow of heat through walls are generally applicable in the calculation of the size of evaporators. The heat-flow equation may be expressed in the form:

$$q_c^* = UA(T_2 - T_1) \quad \text{or} \quad A = \frac{q_c^*}{U(T_2 - T_1)} \quad \text{where,}$$

A = surface area required for the evaporator, in sq. ft.

[Note: For finned surfaces, it is not practical to calculate the effective coil area because the transfer of heat is variably affected by (1) the size of the fins with relation to the size of the tubing, (2) the number of fins per inch, and (3) the type of contact between the fins and tubing.]

q_c^* = the capacity of the compressor in B.t.u./hr. [Note: This value (q_c^*) is for the capacity of the compressor actually selected rather than for the calculated capacity of the compressor (q_c). See "Selection of Compressor Size." If the capacity of the compressor is given in ton of refrigeration (q_{ct}^*), q_{ct}^* may be converted to q_c^* by means of the following equation:

$$q_c^* = (q_{ct}^*)(12,000 \text{ B.t.u./hr.})/(\text{ton of refrigeration})$$

as is illustrated in problem 8.]

U = overall coefficient of heat transfer, in $\frac{(\text{B.t.u./hr.})}{(\text{ft.}^2)(^\circ\text{F.})}$

T_2 = temperature of surrounding medium, such as the air in the refrigerator, in $^\circ\text{F.}$

T_1 = temperature of the refrigerant in the evaporator (evaporative temperature), in $^\circ\text{F.}$

The following discussions and calculations pertain to evaporators used in cold-storage rooms and are limited to (1) bare pipe coils or tubing, (2) finned pipe coils, (3) refrigerated plates, and (4) blower-type unit coolers.

Bare Pipe Coils or Tubing

Bare pipe coils and tubing are most generally applied in liquid cooling, where the coils are submerged, as in an immersion freezer, or in installations in which air temperatures are to be maintained below 34° F., as in cold-storage rooms.

The following is a discussion of the overall-heat-transfer coefficients of cold-storage-room coils and the method of determining the amount of coil surface necessary for a particular installation.

Overall-Heat-Transfer-Coefficient Values

Overall-heat-transfer-coefficient values for pipe coils^{8/} with gravity air circulation range from 1.6 to 2.3 $\frac{\text{B.t.u.}}{\text{hr.}} \frac{1}{(\text{ft.}^2)(^\circ\text{F.})}$, according to

most manufacturers' data. If the temperature differences are quite wide, these heat-transfer values are found to be somewhat larger, owing to the increased circulation of air.

For storage rooms maintained at 0° F., by the use of a direct-expansion system and bare pipe coils at -10° F., a coefficient of heat transfer $U = 1.6 \frac{\text{B.t.u.}}{\text{hr.}} \frac{1}{(\text{ft.}^2)(^\circ\text{F.})}$ may be assumed.

Determination of Required Coil Area

The coil area is determined by solving for A in the basic heat flow equation:

$$A = \frac{q_c^*}{U(T_2 - T_1)}$$

The following problem shows how the required area of coil surface and length of pipe is determined:

^{8/} If these coils are in the form of shelves in direct contact with the fishery product, heat transfer is generally considered to be increased by 15 to 25 percent. If the coils are used in liquid-cooling applications, the heat-transfer coefficients may be increased tenfold over those in air-cooling applications, depending upon the precise conditions of application.

Problem 8

- Given:
1. Refrigerator room at 0° F.
 2. $1\frac{1}{4}$ -inch-pipe-coil evaporator.
 3. Evaporative temperature of -10° F.
 4. 2-ton ammonia compressor ($q_{ct}^{*} = 2$ tons of refrigeration)

- To find:
- (1) The square feet of evaporator surface (A) required.
 - (2) The total length of $1\frac{1}{4}$ -inch pipe required.

Solution: (1) Square feet

$$A = \frac{q_c^{*}}{U(T_2 - T_1)}$$

$$= \frac{24,000}{(1.6)(10)}$$

$$= 1,500 \text{ sq. ft. of evaporator surface required}$$

$$q_{ct}^{*} = 2 \text{ ton of refrigeration.}$$

$$1 \text{ ton of refrigeration} = 12,000 \text{ B.t.u./hr.}$$

$$q_c^{*} = 2 \times 12,000 = 24,000 \text{ B.t.u./hr.}$$

$$U = 1.6 \frac{(\text{B.t.u./hr.})}{(\text{ft.}^2)(^{\circ}\text{F.})}$$

$$T_1 = -10^{\circ}\text{ F.}$$

$$T_2 = 0^{\circ}\text{ F.}$$

$$T_2 - T_1 = 10^{\circ}\text{ F.}$$

(2) Total length

$$1\frac{1}{4}\text{-in. pipe} = 2.30 \text{ linear ft./sq.ft. (from table 10)}$$

$$\text{required length} = 1,500 \times 2.3 = 3,650 \text{ ft.}$$

Finned Pipe Coils

Finned pipe coils are used to provide the necessary refrigeration effect in chill rooms (34° to 40° F.) and in cold-storage rooms (-20° to 0° F.). At temperatures above 34° F. , frost does not accumulate on the coils, and coils with 6 to 8 fins per inch of length can be used. In low-temperature applications (temperatures below 0° F.), however, the number of fins is generally reduced to one to three fins per inch of length in order to allow for the build-up of frost. Finned coils used in low-temperature applications are designed with built-in artificial defrosting systems.

Table 10.—Outside surface areas of copper tubing and of steel and wrought-iron pipe

Nominal size of copper tube	Outside surface areas of copper tube
<u>Inches</u>	<u>Linear ft. per sq. ft.</u>
3/8	7.64
1/2	6.11
5/8	5.09
3/4	4.36
7/8	3.40
Nominal size of steel and wrought-iron pipe	Outside surface area of steel and wrought-iron pipe
<u>Inches</u>	<u>Linear ft. per sq. ft.</u>
1/2	4.55
3/4	3.64
1	2.90
1 1/4	2.30
1 1/2	2.01
2	1.61

Overall-Heat-Transfer-Coefficient Values

The overall-heat-transfer-coefficient values for direct-expansion finned pipe coils vary greatly with the coil design and with the specific application. Heat-transfer coefficients for various applications of finned-pipe coils have been established by each coil manufacturer for his products. The manufacturer's data should therefore be employed in the selection of a coil for a particular use. The data presented by a coil manufacturer is similar to that shown in table 11.

The following problem shows how to select from the manufacturer's catalogue the coil of proper size for a small walk-in cooler:

Problem 9

- Given: 1. Load requirement of 6,000 B.t.u./hr. (q_c^*).
 2. Room temperature of 35° F.
 3. Fin coil, 120 in. long with 3 fins per in.

To find: Type of coil in table 11 for installations with temperature difference of (1) 15° F. and (2) 17° F.

Table 11.--Partial listing of typical capacity ratings and data for finned tube coils

Designation of coil ^{1/}	Tubes in coil	Capacity ratings for temperature differences ^{2/} and fin spacing of:			
		1° F.		15° F.	
		1/2 inch	1/3 inch	1/2 inch	1/3 inch
Type	Number	<u>B.t.u. per hr. per inch of finned length per 1°F.</u>		<u>B.t.u. per hr. per inch of finned length per 15°F.</u>	
A	1	0.27	0.33	4.1	5
B	2	0.55	0.67	8.2	10
C	3	0.82	1.00	12.3	15
D	4	1.09	1.33	16.4	20
E	5	1.37	1.67	20.5	25
F	6	1.64	2.00	24.6	30
G	7	1.91	2.33	28.7	35
H	8	2.18	2.67	32.8	40
I	9	2.46	3.00	36.9	45
J	10	2.73	3.33	41.0	50

^{1/} Length of coil to be specified after designation of type.

^{2/} Temperature difference equals temperature of refrigerator box minus temperature of refrigerant in coil.

Solution: (1) To meet the 15° F. requirement, convert the given load data (q_c^*) to a per-inch-of-fin-length basis:

$$\frac{(6,000 \text{ B.t.u./hr.})}{(120 \text{ in.})(15^\circ \text{ F.})} = 50 \frac{(\text{B.t.u./hr.})}{(\text{in.})(15^\circ \text{ F.})}$$

Select coil J (1/3-inch fin spacing, 120-inch length) from table 11 to meet the requirements of $50 \frac{(\text{B.t.u./hr.})}{(\text{in.})(15^\circ \text{ F.})}$ for the temperature difference of 15° F.

(2) To meet the 17° F. requirement, which is not listed in the table, express the B.t.u. load on a per-inch-of-fin-length-per-1-degree basis:

$$\text{Thus, } \frac{(6,000 \text{ B.t.u./hr.})}{(120 \text{ in.})(17^\circ \text{ F.})} = 2.94 \frac{(\text{B.t.u./hr.})}{(\text{in.})(1^\circ \text{ F.})}$$

Now enter table 11 and select coil I (1/3-inch fin spacing, 120-inch length) in the 1° F. column for a fin spacing of 1/3 inch, since $3.00 \frac{(\text{B.t.u./hr.})}{(\text{in.})(1^\circ \text{ F.})}$ is close to 2.94.

Note: Coil I (1/3-inch fin spacing, 120-inch length) if used in an installation with a temperature difference of 15° F., has a capacity of $3.0 \times 15 = 45 \frac{\text{(B.t.u./hr.)}}{\text{(in.)}(15^\circ \text{ F.})}$. This same coil, if used in an installation with a temperature difference of 17° F., has a capacity of $3.00 \times 17.0 = 51 \frac{\text{(B.t.u./hr.)}}{\text{(in.)}(17^\circ \text{ F.})}$ or $= 6,120 \frac{\text{(B.t.u./hr.)}}{(120 \text{ in.})(17^\circ \text{ F.})}$

Refrigerated Plates

Refrigerated plates of various types are used for shelf surfaces in freezer rooms, in display cases, in low-temperature storage rooms, and in liquid-chilling tanks.

Overall-Heat-Transfer-Coefficient Values

According to most manufacturers' data, overall-heat-transfer-coefficient values of 2.0 to 2.5 $\frac{\text{(B.t.u./hr.)}}{\text{(ft.}^2\text{)(}^\circ\text{F.)}}$ have been found for plates

used in still air at 40° F., considering both sides of the plates as being effective and assuming them to be free of frost. Ratings of 2.0 and lower have been given for plates used in air at 0° F., assuming some frost accumulation^{9/}.

For rooms at 0° F., the average overall-heat-transfer coefficient for plates is assumed to be 2.0 $\frac{\text{(B.t.u./hr.)}}{\text{(ft.}^2\text{)(}^\circ\text{F.)}}$

Determination of Required Plate Area

The required plate area is determined by solving for A in the basic heat-flow equation:

$$A = \frac{q_c^*}{U(T_2 - T_1)}$$

The following problem shows how to calculate the number of square feet of evaporator surface required:

^{9/} If the plates are utilized as freezing-shelf surfaces for freezing food products, the ratings are increased by 15 to 25 percent.

Problem 10

- Given: 1. Load requirement of 24,000 B.t.u./hr. (q_c^*).
2. Refrigeration room at 0° F.
3. Refrigeration effect to be furnished by overhead refrigerator plates at -16° F.

To find: The number of square feet of refrigerator plates (A) required (both sides of plates are effective).

Solution: Substitute given data in equation:

$$\begin{aligned} A &= \frac{q_c^*}{U(T_2 - T_1)} & q_c^* &= 24,000 \text{ B.t.u./hr.} \\ &= \frac{24,000}{2(16)} & U &= 2.0 \frac{\text{(B.t.u./hr.)}}{(\text{ft.}^2)(\text{°F.})} \\ &= 750 \text{ sq. ft. (both sides effective)} & T_1 &= -16^\circ \text{ F.} \\ & & T_2 &= 0^\circ \text{ F.} \\ & & T_2 - T_1 &= 16^\circ \text{ F.} \end{aligned}$$

Blower-type Unit Coolers

The blower-type unit coolers are principally used in maintaining temperatures above 34° F. on a natural defrost cycle, but they may be used in low-temperature applications if a method of artificial defrosting is incorporated in their design. Owing to the more rapid air circulation with this type of cooler, there is danger of product dehydration if the difference between the temperature of the air and that of the coil is too great. For ice-glazed fish, most manufacturers list the maximum permissible difference in temperature as 16° F. and the maximum air velocity as 60 feet per minute (American Society of Refrigerating Engineers Design Data Book). For unglazed fish, the temperature difference should not exceed 10° F.

Method of Rating

It is not practical to calculate heat-transfer rates for unit coolers because of the many variables involved. Instead, the coolers are rated in B.t.u. per hour at a specified temperature difference. Thus, one manufacturer lists data for his unit coolers in a manner similar to that used in table 12.

Selection of Suitable Unit Cooler

In the selection of a suitable unit cooler, the following factors should be considered:

Table 12.--Typical partial listing of capacity ratings for unit coolers^{1/}

Designation of cooler	Unit cooler capacity ratings for specified temperature differences of: ^{2/}		
	10° F.	15° F.	20° F.
<u>Type</u>	<u>B.t.u. per hr.</u>	<u>B.t.u. per hr.</u>	<u>B.t.u. per hr.</u>
A	900	1,350	1,800
B	3,000	4,500	6,000
C	6,000	9,000	12,000
D	9,000	13,500	18,000
E	10,000	15,000	20,000
F	12,000	18,000	24,000
G	24,000	36,000	48,000

^{1/} A manufacturer's table shows a greater number of in-between sizes than are shown in this sample table.

^{2/} Temperature difference equals temperature of refrigerator minus temperature of refrigerant in coil.

1. The temperature of installation (high temperature versus low temperature).
2. If the installation is for low temperature, the method of defrost (hot gas, water, or electric).
3. The temperature difference between the air in the refrigerator room and the refrigerant in the unit cooler.
4. The load requirement in B.t.u. per hour.

The following problem shows how to select a unit cooler from manufacturer's data:

Problem 11

- Given:
1. Refrigerator room at 0° F.
 2. Hot-gas defrost.
 3. Unit cooler with fin-coil temperature (a) of -10° F. or (b) of -12° F.
 4. Load requirement of 12,000 B.t.u. per hour (q_c^*).

To find: (1) Applicable type unit in table 12 for fin-coil temperature difference of 10° F.

- (2) Applicable type unit in table 12 for fin-coil temperature difference of 12° F.

Solution: (1) For a fin-coil temperature difference of 10° F., the type F unit in table 12 has the proper requirements (12,000 B.t.u./hr.) and would therefore be the unit selected.

- (2) For a fin-coil temperature difference of 12° F., the capacity requirement would be calculated as follows: The capacity needed on the basis of a 12° F. temperature difference would be: $\frac{12,000 \text{ B.t.u./hr.}}{12^\circ \text{ F. difference}}$

This capacity, on the basis of a 1° F. temperature difference, would be: $\frac{1,000 \text{ B.t.u./hr.}}{1^\circ \text{ F. difference}}$

And this capacity, on the basis of a 10° F. temperature difference, would be: $\frac{10,000 \text{ B.t.u./hr.}}{10^\circ \text{ F. difference}}$

The type-E unit (capacity of 10,000 B.t.u. per hour at a temperature difference of 10° F.) would therefore be the one selected from table 12.

OVERALL ILLUSTRATIVE PROBLEM

The following overall illustrative problem shows how the preliminary calculations required in the construction of a cold-storage room might be made.

The Problem

A fish processor in the New England area had need to construct a nonpallatized 0° F. cold-storage room with a capacity for 25,000 pounds of packaged fillets in cartons. Two thousand pounds of the product was to be cooled from 10° to 0° F. every 24 hours.

Information Required

The processor had to determine:

1. Thickness of insulation.
2. Size of room.
3. Area of insulation.
4. Size of compressor.
5. Size and number of refrigerated plates.

Determination of Thickness of Insulation

The processor decided to insulate his cold-storage room with cork.

Since the cold-storage temperature was 0° F. and the plant was located in the northern part of the United States, table 3 showed that the required thickness of insulation was 6 inches.

Determination of Size of Room

Length of Room

The space situation fixed the outside length of the room at 15 feet. Inasmuch as the processor decided to line the room inside and outside with 1/2-inch-thick plywood, the inside length of the room was fixed at 13.8 feet (15 feet minus 1 foot 2 inches).

Width of Room

The processor found that the density of his product was 55 pounds per cubic foot (see "Walk-in Freezers and Coolers" in this section). He decided to limit the height of the product to 6 feet, for easy stacking, and to have an aisle 4.5 feet wide running the length of the room. To determine the width of the room, he made the following calculations:

$$\begin{aligned}
 \text{Volume of product} &= \frac{25,000}{55} \\
 &= 455 \text{ ft.}^3 \\
 \\
 \text{Area of floor occupied by product} &= \frac{455}{6} \\
 &= 75.8 \text{ ft.}^2 \\
 \\
 \text{Area of floor occupied by aisle} &= (4.5)(13.8) \\
 &= 62.1 \text{ ft.}^2 \\
 \\
 \text{Total area of floor} &= 75.8 + 62.1 \\
 &= 137.9 \text{ ft.}^2 \\
 \\
 \text{Width of room (inside dimension)} &= \frac{137.9}{13.8} \\
 &= 9.99 \\
 &= 10 \text{ ft. (in round numbers)} \\
 \\
 \text{Width of room (outside dimension)} &= 10 + \frac{2(\frac{1}{2} + 6 + \frac{1}{2})}{12} \\
 &= 11.2 \text{ ft.}
 \end{aligned}$$

Height of Room

Refrigerated plates 12 inches high were selected to provide the necessary refrigeration effect. The inside height of the room therefore was equal to the product-piling height (6 feet) plus the clearance between

plates and product (6 inches) plus the clearance between plates and ceiling (6 inches) or to a total of 8 feet.

Floor construction--consisting of $\frac{1}{2}$ -inch-thick plywood, 6-inch-thick corkboard, $\frac{1}{2}$ -inch-thick plywood, and 4-inch-thick concrete slab--and ceiling construction--consisting of $\frac{1}{2}$ -inch-thick plywood, 6-inch-thick corkboard, and $\frac{1}{2}$ -inch-thick plywood--when added to the inside height, gave an outside height of 9.5 feet.

Volume of Room

The inside volume of the room was thus fixed at 1,104 cubic feet (13.8 x 10 x 8).

Determination of Area of Insulation

Inasmuch as the required area of insulation is very nearly equal to the outside surface of the room, the processor made the following calculations:

Area of front and rear walls	= 2 x 9.5 x 11.2 = 213 ft. ²
Area of side walls	= 2 x 9.5 x 15 = 285 ft. ²
Area of roof and floor	= 2 x 11.2 x 15 = 336 ft. ²
Area of outside surface of room	= 213 + 285 + 336 = 834 ft. ²
Area of insulation required	= 834 ft. ²

Determination of Size of Compressor

In the selection of the proper size of compressor, five factors had to be considered:

1. Calculated total heat-gain load.
2. Hours of operation of compressor.
3. Calculated capacity of compressor.
4. Evaporative temperature.
5. Available size of compressor.

Calculated Total Heat-Gain Load (q')

The formula the processor used for determining the total heat-gain load was:

$$q' = 1.10(q'_w + q'_p + q'_s + q'_m) \quad \text{where,}$$

q'_w is the wall-heat-gain load, q'_p is the product-heat-gain load, q'_s is the service-heat-gain load, and q'_m is the miscellaneous-heat-gain load. The figure 1.10 provides a factor of safety of 10 percent.

Wall-heat-gain load (q'_w).--From a study of the weather reports in the files of the local newspaper, the processor decided that 90° F. would be a reasonable outside design temperature. Using the resulting temperature difference of 90° F. (90° F. outside design temperature minus 0° F. cold-storage temperature) and the specified 6 inches of coil insulation, he obtained 108 B.t.u. per square foot per 24 hours from table 2. He then calculated the wall-heat-gain load as:

$$\begin{aligned} q'_w &= (108)(834) \\ &= 90,100 \text{ B.t.u./24 hr.} \end{aligned}$$

Product-heat-gain load (q'_p).--Taking 0.4 as the specific heat of the frozen packaged fillets, he calculated the product-heat-gain load as:

$$\begin{aligned} q'_p &= (2,000)(0.4)(10) \\ &= 8,000 \text{ B.t.u./24 hr.} \end{aligned}$$

Service-heat-gain load (q'_s).--By interpolation in table 5 for a cold-storage room with a volume of 1,104 cubic feet (one door to the room), the processor obtained a value of 16.8 air changes per 24 hours. Then assuming 90 percent relative humidity for the air outside and 60 percent relative humidity for the air inside of the cold-storage room, he obtained 3.56 B.t.u. per cubic foot from table 6, and calculated the service-heat-gain load as:

$$\begin{aligned} q'_s &= (16.8)(1,104)(3.56) \\ &= 66,100 \text{ B.t.u./24 hr.} \end{aligned}$$

Miscellaneous-heat-gain load.--To insure adequate light, the processor decided to use two 100-watt bulbs. Taking 1 watt as being equal to 3.42 B.t.u. per hour, he calculated the heat-gain-load from the lights as:

$$\begin{aligned} q'_{el} &= (2)(100)(3.42)(24) \\ &= 16,400 \text{ B.t.u./24 hr.} \end{aligned}$$

Estimating that one man working intermittently over an 8-hour day could handle the product, he obtained the value of 1,300 B.t.u. per hour from table 8, and calculated the heat-gain load for the workman as:

$$\begin{aligned} q'_o &= (1,300)(24) \\ &= 31,200 \text{ B.t.u./24 hr.} \end{aligned}$$

The total miscellaneous heat load was then calculated as:

$$\begin{aligned} q'_m &= 16,400 + 31,200 \\ &= 47,600 \text{ B.t.u./24 hr.} \end{aligned}$$

Calculated value of q' .--Having determined the four separate heat-gain loads, the processor calculated the total heat-gain load as:

$$\begin{aligned} q' &= 1.10(90,100 + 8,000 + 66,100 + 47,600) \\ &= 233,000 \text{ B.t.u./24 hr.} \end{aligned}$$

Hours of Operation of Compressor (t_c)

Inasmuch as the installation was a small one in which a manual defrost cycle was to be used, the compressor would operate 18 hours per day [see "Hours of Operation of Compressor (t_c)" in this section].

Calculated Capacity of Compressor (q_c)

Using the formula $q_c = \frac{q'}{t_c}$, the processor calculated the required capacity of the compressor as:

$$\begin{aligned} q_c &= \frac{233,000}{18} \\ &= 12,900 \text{ B.t.u./hr.} \end{aligned}$$

Evaporative Temperature

Since the product was adequately packaged, it was decided that an evaporative temperature of -15° F. could be used.

Selected Size of Compressor (q_c^*)

The processor, on looking through the various manufacturer's catalogues, found that a typical catalogue listed a model E as having a capacity rating of 11,500 B.t.u. per hour (water cooled; Freon 12; evaporative temperature -16° F.) and a model F as having a rating of 13,200 B.t.u. per hour (under the same conditions). He therefore chose model F.

He found that this model was rated at 14,800 B.t.u. per hour at -12° F. By interpolating (between -12° F. and -16° F.) he found the capacity of the selected compressor (-15° F. evaporative temperature) to be:

$$\begin{aligned} q_c^* &= 13,200 + \frac{(14,800 - 13,200)(16-15)}{(16-12)} \\ &= 13,600 \text{ B.t.u./hr.} \end{aligned}$$

(Note that owing to the fact that compressors are manufactured only in certain sizes, the capacity of compressor selected was about 5.4 percent greater than the required capacity of 12,900 B.t.u. per hour. Thus the room had an additional reserve of refrigeration capacity.)

Determination of the Size and Quantity of Refrigerated Plates

By consulting a catalogue listing refrigerated plates, the processor found that the heat-transfer value (U) of one manufacturer's plates under the conditions of the problem was 2.0 B.t.u. per square foot per hour per degree Fahrenheit. Since the temperature difference between the room and the refrigerant was 15 degrees Fahrenheit, he calculated the total cooling surface required (A) from the basic equation:

$$\begin{aligned} q_c^* &= UA(T_2 - T_1) \quad \text{or} \quad A = \frac{q_c^*}{(U)(T_2 - T_1)} \\ &= \frac{13,600}{(2.0)(15)} \\ &= 454 \text{ ft.}^2 \end{aligned}$$

Inasmuch as the length of the room was 13.8 feet, plates 12 feet long could be used.^{10/} The processor therefore made the following calculations:

$$\begin{aligned} \text{Minimum number of plates required} &= \frac{454}{1 \times 12 \times 2} \text{ (plates 12 in. deep,} \\ &\quad \text{12 ft. long, effective} \\ &\quad \text{both sides.)} \\ &= 18.9 \text{ plates} \end{aligned}$$

$$\text{Actual number of plates required} = 20 \text{ plates (to give a balanced system).}$$

In selecting the plates, the processor found that four banks of plates with five plates per bank would be satisfactory.

^{10/} Refrigerated plates are generally furnished in lengths of 5, 6, 7, 9, or 12 feet and in banks of four, five, or six plates per bank. The manufacturer's recommendations must be followed in the selection of the number of plates per bank so that the pressure drop through the system will not be too great.

BIBLIOGRAPHY

AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

- 1954-55. Air Conditioning Refrigerating Data Book, Applications volume, Fifth edition. American Society of Refrigerating Engineers, New York.

AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

- 1955-56. Air Conditioning Refrigerating Data Book, Design volume, Ninth edition. American Society of Refrigerating Engineers, New York.

COOK, W. H.

1939. Humidification of freezers. Refrigeration Engineering, vol. 38, No. 4, October, pp. 229-233.

CURRY, E. R.

1953. Refrigerated warehousing industry builds for the future. Industrial Refrigeration, vol. 124, No. 5, May, pp. 15-19.

KING, GUY R.

1951. Basic Refrigeration. Nickerson and Collins Company, Chicago, Illinois.

LENTZ, C. P.

1955. Humidification of cold storages: The jacket system. Canadian Journal of Technology, vol. 33, No. 4, July, pp. 265-278.

MOTZ, WILLIAM H.

1947. Principles of Refrigeration, Third edition, revised. Nickerson and Collins Company, Chicago, Illinois.

PETERSON, H.

1953. Modern cold storage plant design. Industrial Refrigeration, vol. 125, No. 5, November, p. 23.

RUPP, A. W.

1954. Frost heaving of freezer room floors. Industrial Refrigeration, vol. 126, No. 5, November, pp. 13-14.

YOUNG, O. C.

1952. The jacket principle. Canadian Refrigeration Journal, vol. 18, No. 11, November, pp. 21-22, 52.

ZAKAN, D. L.

1951. Warehouse adds new section. Industrial Refrigeration, vol. 120, No. 1, January, pp. 23-26.

ACKNOWLEDGMENT

Much of the tabular data in this section were adapted from Air Conditioning Refrigerating Data Book, Design Volume, Ninth edition (1955-56), published by The American Society of Refrigerating Engineers.

The cover photographs were furnished through the courtesy of Quincy Market Cold Storage and Warehouse Company (photograph on upper left side), Industrial Refrigeration (photograph on lower left side), and American Plate Freezer Corporation (photograph on right side).

SECTION 2

REFRIGERATION EQUIPMENT

By Joseph W. Slavin, Refrigeration Engineer *

TABLE OF CONTENTS

	Page
Introduction	78
Compression system	78
Principles of operation	78
Single-stage compression system	79
Multiple-stage compression system	80
Two-stage compression system	80
Three-stage compression system	82
Equipment	82
Compressors	82
Reciprocating compressors	83
Classification	83
Compressor speed	83
Capacity regulation	84
Cylinder bypass	85
Clearance pockets	85
Speed regulation	86
Multiple compressors in parallel	86
Compressor size and method of drive	87
Selection of a reciprocating compressor	87
Centrifugal compressors	88
Rotary compressors	89
Condenser	89
Receiver	90
Expansion valve	91
Evaporator	92
Auxiliary equipment and controls	92
Auxiliary equipment	92
Oil separator	92
Drier	92
Sight glass	93
Heat exchanger	93
Controls	93
Absorption system	94

* Fishery Technological Laboratory, East Boston 28, Massachusetts

	Page
Principle of operation	95
Equipment	96
Absorber	98
Aqua pump	98
Heat exchanger	99
Generator	99
Distillation column or analyzer	99
Reflux meter	99
Comparison between the absorption and compression systems . .	100
Evaporators	101
Classification	101
Direct-expansion evaporators	101
Indirect-expansion evaporators	102
Application	103
Cold-storage rooms	103
Quick freezers	103
Defrosting of evaporators	104
Water defrosting	104
Hot-gas defrosting	105
Refrigerants	105
Ammonia	105
Advantages of ammonia	106
Disadvantages of ammonia	106
Freon 12 (Dichlorodifluoromethane)	106
Advantages of Freon 12	106
Disadvantages of Freon 12	106
Carbon dioxide	107
Advantages of carbon dioxide	107
Disadvantages of carbon dioxide	107
Methyl chloride	107
Advantages of methyl chloride	107
Disadvantages of methyl chloride	107
Freon 11 (Trichloromonofluoromethane)	107
Freon 22 (Monochlorodifluoromethane)	108
Bibliography	108

ILLUSTRATIONS

Figure 1.--Flow diagram of the basic single-stage compression system	79
Figure 2.--Schematic diagram of a Freon 12 two-stage compression system, showing all the auxiliary equipment	81

	Page
Figure 3.--An ammonia, single-acting reciprocating compressor	84
Figure 4.--Ammonia double-acting reciprocating compressors .	84
Figure 5.--An ammonia, single-acting reciprocating compressor with variable capacity control	85
Figure 6.--A centrifugal compressor with condenser and brine cooler	88
Figure 7.--A 3-hp. Freon 12 compressor with an air-cooled condenser	90
Figure 8.--Cross-sectional view of a single-outlet thermostatic expansion valve for Freon 12	91
Figure 9.--A low-temperature thermostat	93
Figure 10.--A low-pressure switch	94
Figure 11.--Flow diagram of the absorption system	95
Figure 12.--View of an absorption refrigeration unit	97
Figure 13.--Diagrammatic view of an absorption system as installed on a fishing vessel	98
Figure 14.--Finned pipe coils in a cold-storage room	103
Figure 15.--Blower-type cooling units in a refrigerated room	104

INTRODUCTION

Refrigeration is the act of producing and maintaining in a substance or space a temperature below that of the surrounding atmosphere.

The withdrawal of heat from the substance or space to accomplish the desired degree of refrigeration below 32° F. requires the use of any one of several refrigerating processes. Each of these depends upon the use of a substance, called the refrigerant, that can be readily converted from a liquid into a vapor or gas, and also from a vapor or gas back into a liquid within a reasonably narrow range of pressures.

The refrigerant, if first stored as a liquid under pressure, then allowed to flow at reduced pressure through a set of pipe coils in the closed system, will withdraw heat from the medium surrounding the coils during the vaporizing stage. The heat so absorbed is removed from the refrigerated area when the vapor or gas returns to that portion of refrigerating equipment designed to cool and compress it again to the liquid state for reuse.

Although a number of refrigerating processes have been developed, the two in commercial use today are the compression system and the absorption system. In this section the two systems will be discussed, and their principal machinery components described. There will also be a discussion of commercial evaporators and of refrigerants.

COMPRESSION SYSTEM

The compression system was first developed for practical use in the middle 1880's, and it became widely accepted for mechanical refrigeration purposes in the early 1900's. In this system, a continuous refrigeration cycle takes place that alternately evaporates the liquid refrigerant at low pressure and temperature, and condenses the vapor at a high pressure and temperature. This continuous refrigeration cycle was made possible by years of hard work and research, which resulted in the development of equipment that would produce a practical, efficient system.

In the early stages of development, large, bulky, and inefficient pieces of equipment were used, resulting in breakdowns and poor operation. As the years progressed, however, small, compact, highly efficient equipment was produced, which resulted in increased use of the compression system for cold-storage plants, quick freezers, home freezers, air conditioning, and many other purposes.

Principles of Operation

The refrigerants commonly employed in the modern compression system are ammonia, Freon 12, Freon 22, carbon dioxide, and methyl chloride.

Of these, ammonia and Freon 12 are the most widely used in commercial plants, because of their many operational and economic advantages.

Compression systems may be either single stage or multiple stage. In the single-stage system, the refrigerant is pumped by means of a single-compression process, whereas in the multiple-stage system, two or more compression processes are used.

Single-stage compression system

The basic equipment in a single-stage compression system consists of a receiver, expansion valve, evaporator, compressor, condenser, and the necessary interconnecting piping and valves. The cycle of operation is as follows (figure 1): The liquid refrigerant, which for purposes of illustration we will assume to be Freon 12, is stored under a pressure of approximately 120 pounds per square inch gauge (p.s.i.g.) in the receiver. From the receiver, it flows through a thermostatically controlled expansion valve to the evaporator coils. The expansion valve, by suitably throttling the refrigerant flow, reduces the pressure from 120 p.s.i.g. to a pressure corresponding to the desired evaporator temperature, thereby producing a mixture of liquid and vapor. The

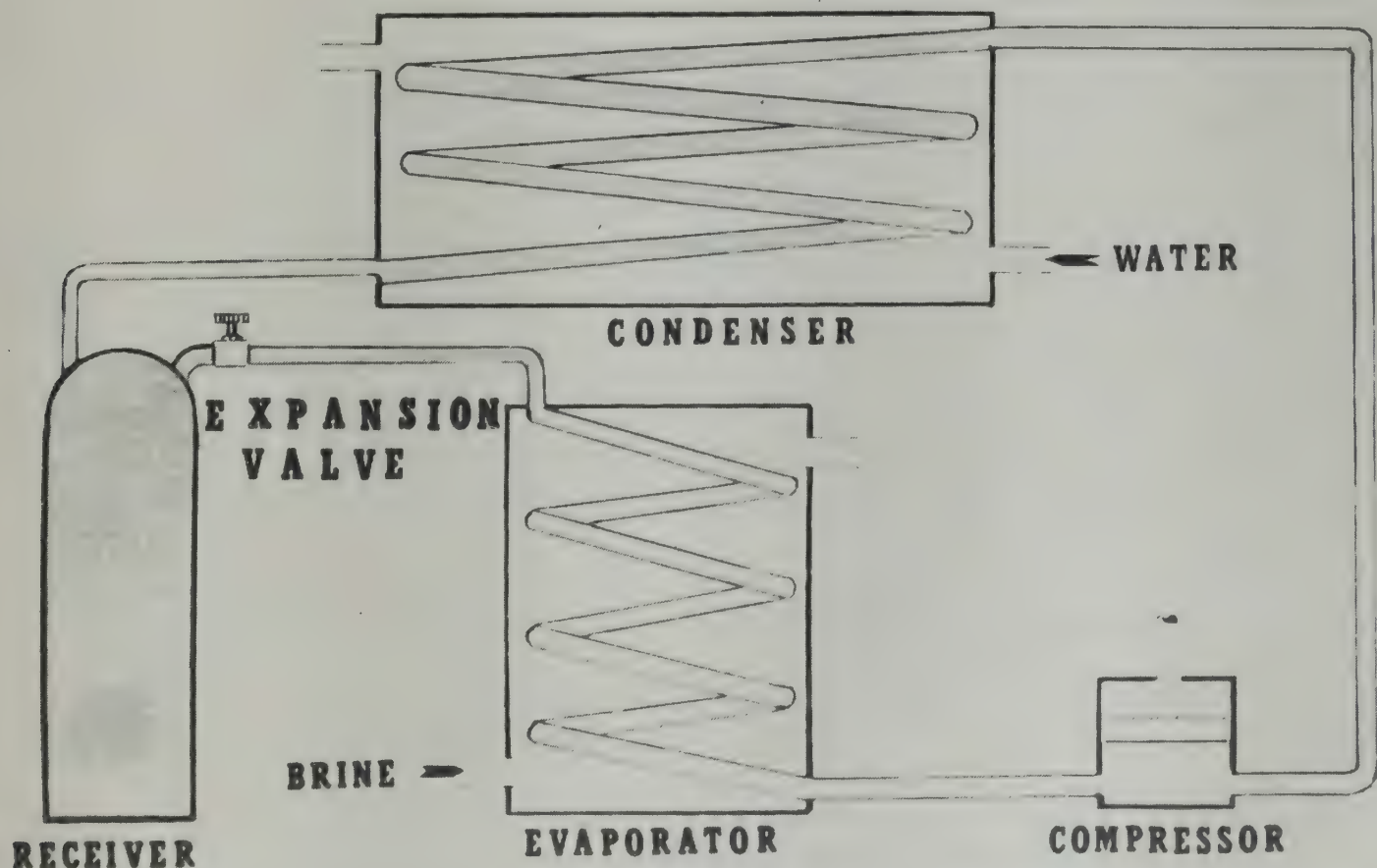


Figure 1.--Flow diagram of the basic single-stage compression system.

liquid then flows through the evaporator coils, where it extracts heat from the products being cooled--brine, in the illustration--and changes to a vapor at approximately the same pressure and temperature as that at which it left the expansion valve.

This vapor then enters the compressor, where it is compressed to 120 p.s.i.g. The compressed gas, after leaving the compressor, is discharged into a condenser, which uses water or air as the cooling medium. The gaseous refrigerant in the condenser is cooled to a liquid, and this liquid then enters the receiver, thereby completing the cycle.

When using refrigerants other than Freon 12 in the compression system--such as ammonia, Freon 22, carbon dioxide, and methyl chloride--the cycle of operation is similar to that described above. However, the operating pressures and specific equipment design for each compression system will vary with the type of refrigerant employed.

Multiple-stage compression system

The use of the single-stage compression system for low-temperature applications is limited by (1) the compression ratio of the compressor, (2) the difference between the evaporator temperature and the discharge temperature, and (3) the capacity of the system in tons of ice melting equivalent^{1/}.

To keep the power requirements and displacement of the compressor at a minimum, two- and three-stage compression systems are used.

Because of the many factors involved in the design of a compression system--such as capacity, evaporative temperature, type of compressor, and refrigerant--there is no clear-cut dividing point as to where a two-stage system should be used instead of a single-stage system, or a three-stage system instead of a two-stage system. However, generally the single-stage system is used for evaporative temperatures of above -20° F., the two-stage system is used for evaporative temperatures of -20° to -75° F., and the three-stage system is used for evaporative temperatures below -75° F.

Two-stage Compression System

In the two-stage system, there are two compressors connected together in series (figure 2). The compressor nearest the evaporator is

^{1/} The refrigeration capacity of a system is measured in tons of ice melting equivalent (i.m.e.). One ton i.m.e. is the rate of cooling afforded by 1 ton of ice at 32° F. melting in 1 day, which is equal to the extraction of 288,000 B.t.u. per day.

referred to as the low-stage compressor, whereas the other one is referred to as the high-stage compressor. Each compressor serves to compress the gas partially so that, upon leaving the high-stage compressor, the gas pressure is the same as it would be upon exit from a single-stage system. The gas from the evaporator, after passing through the low-stage compressor, must be cooled before entering the high-stage compressor; otherwise the excessive heat will damage the high-stage compressor. This cooling of the gas is referred to as "interstage cooling" and is accomplished by either a water-cooled gas cooler or by a flash-type cooler.

In the water-cooled gas cooler, water circulating within tubes cools the gas, which passes around the outside of the tubes.

In the flash-type cooler, part of the liquid refrigerant from the receiver passes through a thermal expansion valve into a liquid cooler, where it (1) cools the liquid going from the receiver to the evaporator and (2) then passes into the discharge line of the low-pressure compressor, where it mixes with the gas entering the high-stage compressor and cools this gas.

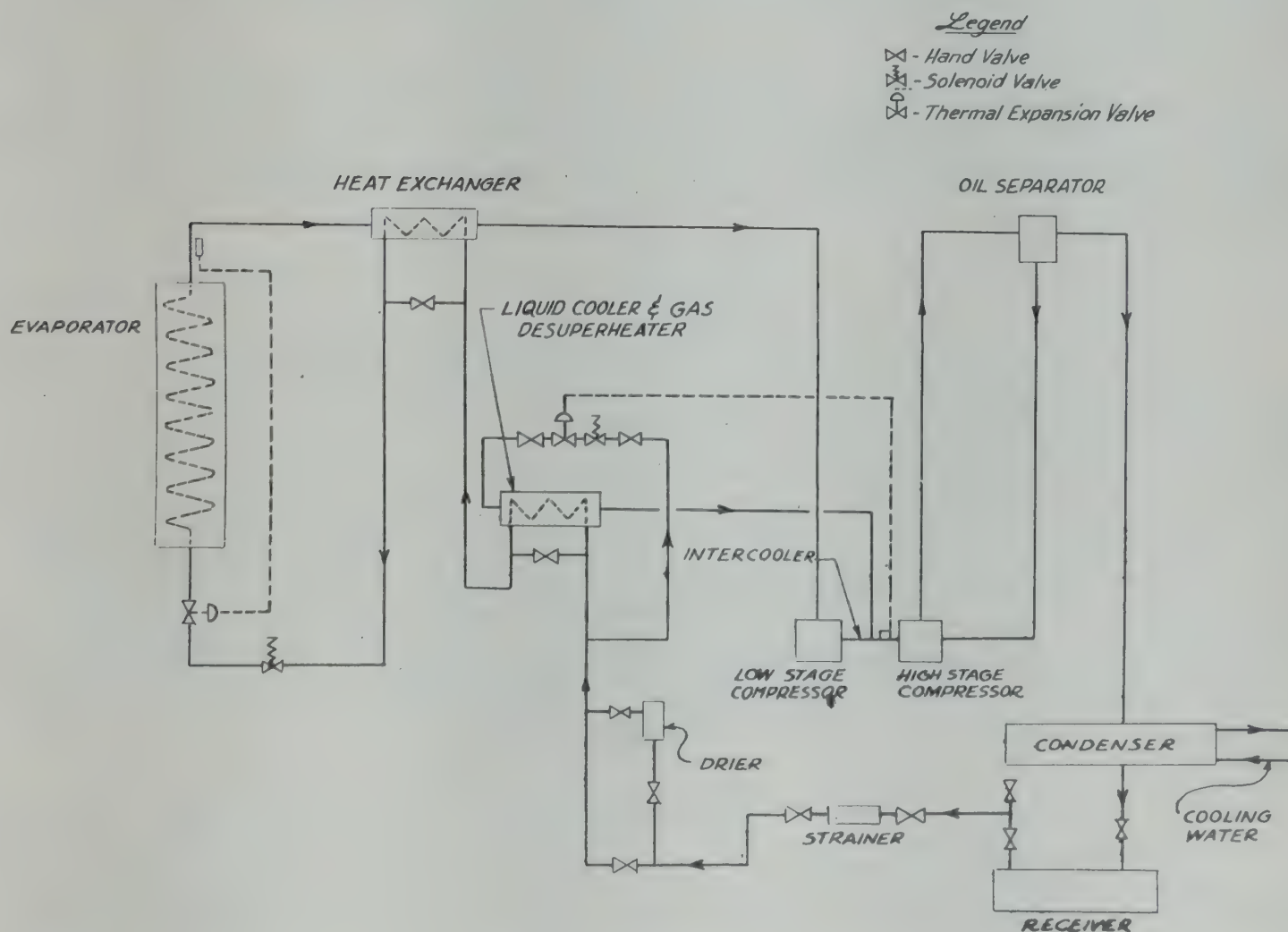


Figure 2.—Schematic diagram of a Freon 12 two-stage compression system, showing all the auxiliary equipment.

The refrigerant, after leaving the high-stage compressor in a two-stage compression system, follows the same path as does the refrigerant leaving the compressor in a single-stage system. The basic equipment used in the two-stage system is also similar to that used in the single-stage system, with the exception of the intercooling assembly and the additional compressor.

Refrigeration compressors are now being manufactured with two stages built into one machine. This unification is accomplished by means of a certain number of the cylinders (usually three) operating on the low stage and the rest (usually one) operating on the high stage. The result is a compact, efficient compressor for low-temperature application.

Three-stage Compression System

The three-stage compression system is similar to the two-stage system except that the compression of the refrigerant is accomplished by three compressors connected in series rather than by two. The three compressors are referred to as low-, intermediate-, and high-stage compressors. The gas between the low and intermediate stage and between the intermediate and high stage is cooled by use of methods similar to those described for the two-stage system.

In the selection of a compression system for low-temperature applications, a refrigeration engineer should be consulted in order to determine the most satisfactory and economical method of handling the specific application involved.

Equipment

In addition to the compressor, condenser, receiver, expansion valve, and evaporator, which form the basic compression system, there are other pieces of machinery that have been added throughout the years in order to improve the performance of the system. These additional pieces have been grouped together under the general classification of "Auxiliary Equipment," which is described later in this section. A description of the specific equipment design employed with each refrigerant would be too lengthy for this publication. Therefore, the following discussion will be limited to a general description of the basic equipment contained in the compression system. Additional information can be obtained from the references at the end of this section.

Compressors

The compressor is referred to as the heart of the compression system. Its principal function is similar to that of a positive-acting pump being used to circulate water from a low-pressure supply to a tank under high pressure. In the compression system, the compressor draws

the refrigerant, which is in the form of a vapor, out of the evaporator at a low pressure and temperature and compresses it to a gas at a higher pressure and temperature. The high pressure enables the refrigerant to flow through the other component pieces of equipment that then put it in a state ready for reuse in the evaporator.

The first compressors used were of the reciprocating type. They were large and uneconomical and ran at the very low speed of 50 revolutions per minute. Many improvements in this type of machine were made in the years following its inception, resulting in a compact, efficient, high-speed machine capable of automatic operation. During the periods when the reciprocating compressor was being improved upon, other machines known as the centrifugal compressor and the rotary compressor were developed for refrigeration purposes. The following is a discussion of these three types of compressors, their uses, and their relative merits.

Reciprocating Compressors

The reciprocating compressor is the most common type of compressor. It is used to supply refrigeration for cold-storage plants, sharp freezers, plate freezers, blast freezers, and many other kinds of freezing apparatus. All reciprocating compressors are basically alike, consisting of pistons, crankshaft, valves, and other component parts. There are many different commercial makes of reciprocating compressors, each employing a slightly different design. As these various designs are too numerous to mention here, this discussion will be concerned with the general design features that are incorporated in one manner or another in the present-day machines.

Classification.—A reciprocating compressor is classified either as single-acting or double-acting. In the single-acting compressor (figure 3), the gas is compressed and discharged at the top of the piston only, whereas in the double-acting compressor (figure 4), both the bottom and top of the piston are used to compress and discharge the gas. In the double-acting compressor, a crosshead and other gear is used to absorb the thrust on the under side of the piston. It is obvious that the double-acting compressor will give a much higher output of gas for the same size unit operating at the same speed. Owing to the extra gear involved, consisting of the crosshead and component parts, it is cheaper to produce the single-acting compressor in the small and medium sizes, and the double-acting compressor in the larger sizes.

Compressor speed.—The speed of a compressor is determined in the original design by the manufacturer, and therefore we will touch on the subject only enough to show the effect of the speed on the size and weight of the unit. If higher rotative speeds are used, compressors can be built that occupy less space and that are lighter in weight per unit of horsepower. The speed depends on the size of the cylinders,

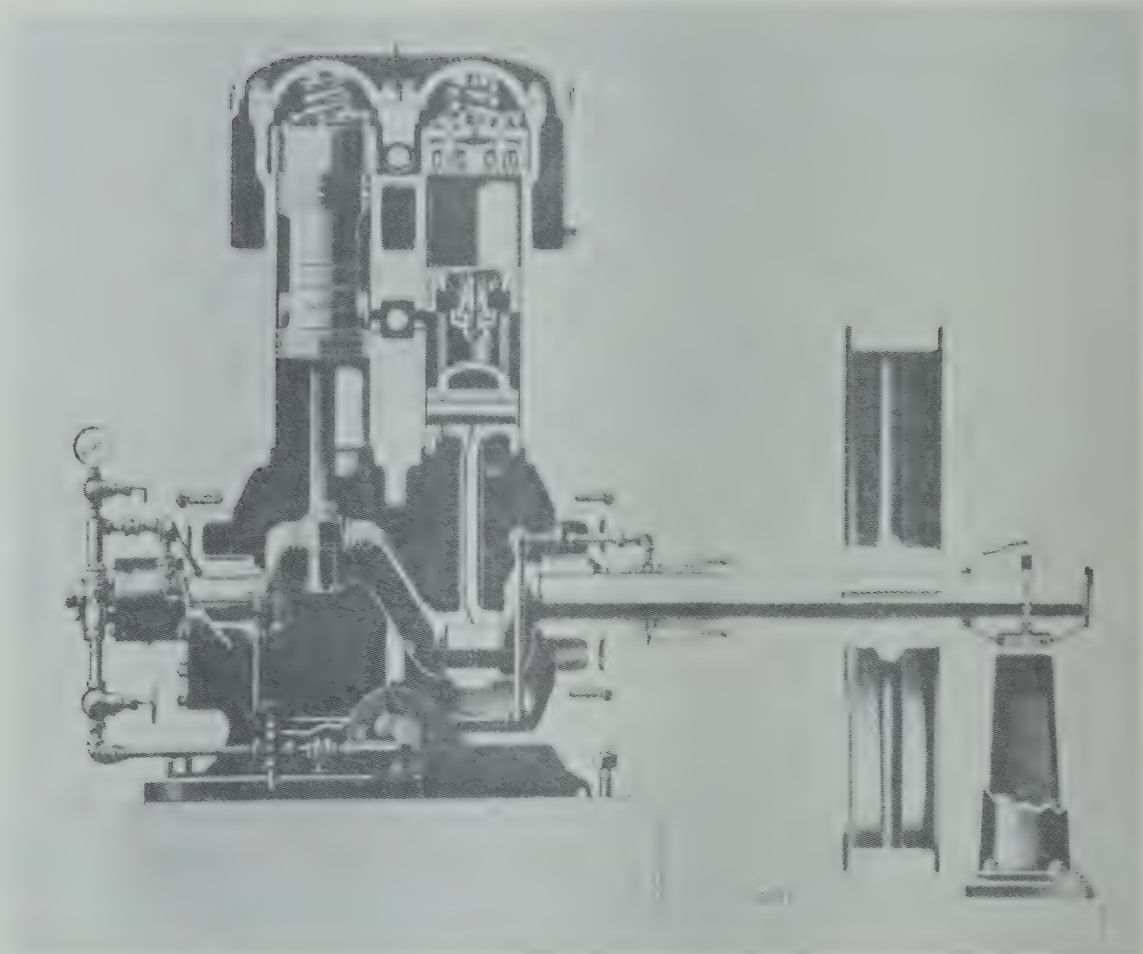


Figure 3.—An ammonia, single-acting reciprocating compressor. In this compressor, the suction gas enters the cylinders through valves in the top of the pistons and is discharged through plate-type valves in the cylinder heads. (Photo courtesy of Frick Company)

the number of cylinders, and the valve action. The cylinders may be arranged in line, radially, or in a v-formation, depending on the manufacturer's design. The trend in compressor design today is toward higher rotative speeds, ranging from 300 to 1,750 r.p.m.

Capacity regulation.—If a compressor is used in a plant where the refrigeration load varies continually, a method of capacity regulation should be employed; otherwise continuous starting and stopping of the machine, which is referred to as "cycling," will occur

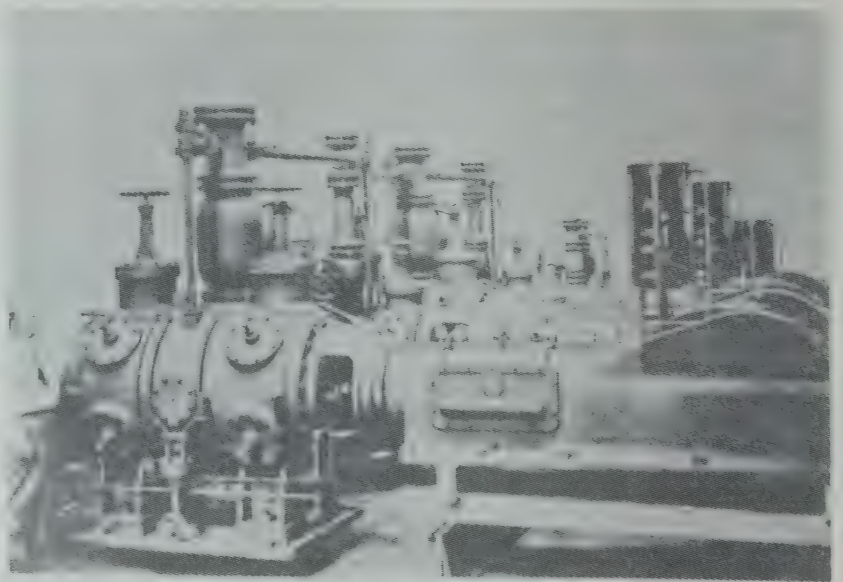


Figure 4.—Ammonia double-acting reciprocating compressors. (Photo courtesy of Frick Company)

when the load is small, and long running periods will occur when the load is large. To make possible the operation of a single compressor at reduced loads, three different methods known as (1) cylinder bypass, (2) clearance pockets, and (3) speed regulation have been employed. In addition, if more than one compressor is available, a system of compressors in parallel can be used. The following is a description of the above mentioned methods of providing capacity regulation along with a discussion of their related merits.

Cylinder bypass.--This method can be used (1) by holding the suction valves open on some of the cylinders, (2) by opening a valve between cylinders where the crank bends are 180 degrees apart, (3) by arranging a bypass at the bottom half of the cylinder so only the upper half is used (double-acting only), or (4) by installing a solenoid valve at the discharge end of some of the cylinders. In the last procedure, some of the gas is made to flow back to the suction line, thereby bypassing the other cylinders.

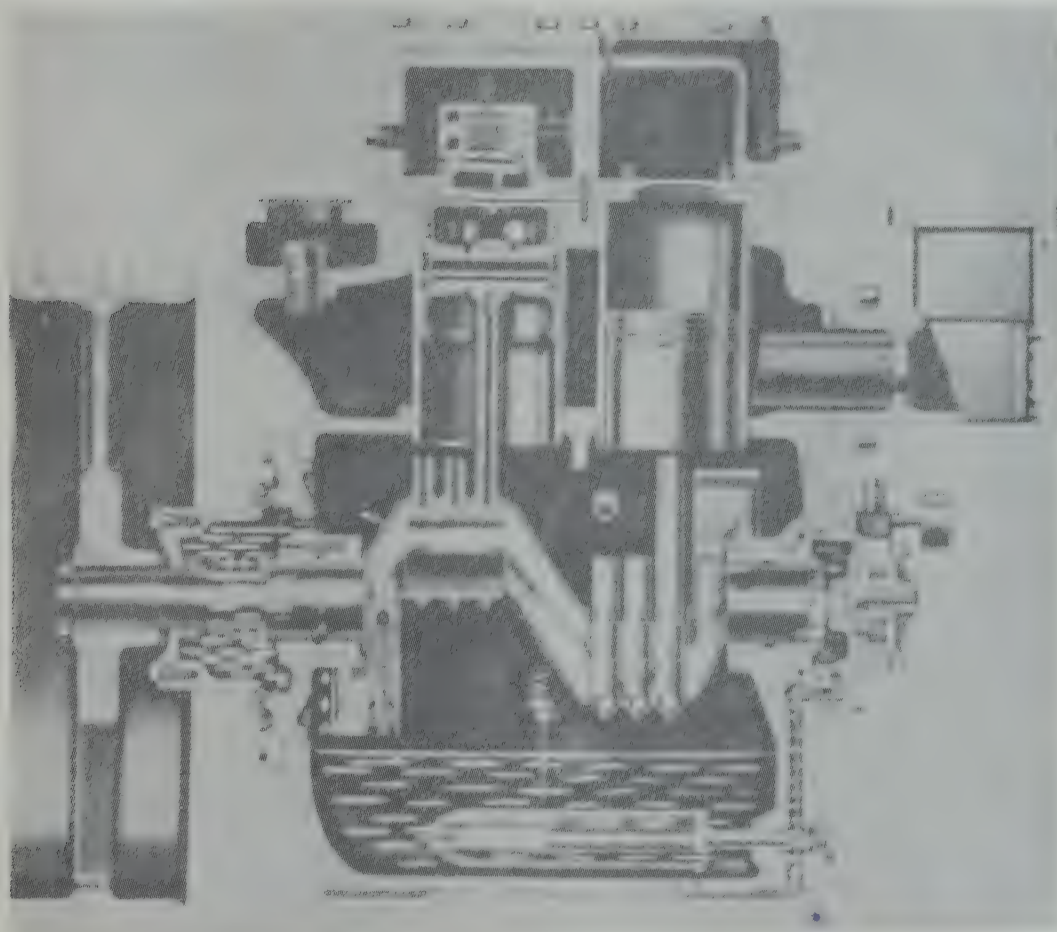


Figure 5.--An ammonia, single-acting reciprocating compressor with variable capacity control. When the solenoid located in the compressor head is de-energized, fingers actuated by a power spring hold open the suction valve strips, reducing the output capacity of the machine. (Photo courtesy of the Worthington Corporation)

The most common type of cylinder bypass is a solenoid valve in a line connected to the discharge of 2, 3, or more cylinders. As the load decreases, the solenoid valve opens, bypassing the hot gas back to the suction line. Thus, the number of cylinders bypassed depends on the load.

Clearance pockets.--Operation of a machine with clearance pockets is similar to that with cylinder bypass, the only difference being in the method of application; the results are the same.

Clearance is the space in the cylinder between the piston, at the end of the compression stroke, and the

suction and discharge valves, when seated. If the clearance is increased at a constant pressure, the amount of vapor circulated will be reduced, thus reducing also the cylinder power and efficiency. This is the principle on which the clearance pocket operates.

Clearance pockets are of two major designs. The first design consists of 2 or 3 chambers connected to the compressor cylinder by means of a valve in each chamber. When the valve is opened, a passageway is opened between the cylinder and chamber, thereby increasing the clearance by the net volume of the clearance pocket, resulting in a lower output of the machine. The second design consists of an auxiliary cylinder and piston connected to the compressor cylinder. The amount of clearance is controlled by moving the auxiliary piston in and out.

The following are some of the disadvantages resulting from the use of cylinder bypasses and clearance pockets:

1. The compressor is operated with only some of its cylinders in use. Power is therefore being expended to bypass the remaining cylinders, resulting in a lower compressor efficiency. For example, a compressor operating at half capacity will consume approximately 70 percent of the power of a compressor operating at full capacity.

2. The lowered efficiency of the compressor results in a greater degree of "superheat"^{2/} upon compression. With Freon 12, the degree of superheat may not be excessive, but with ammonia, where the superheat is excessive, a provision must be made to inject liquid ammonia into the suction line after starting.

Speed regulation.--The capacity of a reciprocating compressor may be controlled by the use of a two-speed, three-phase induction motor or of a rheostat controlling the speed of a direct-current motor. The slowest speed permissible is that at which the oil film in the bearings can be sufficiently maintained to provide proper lubrication. Speed regulation results in a certain degree of inefficiency because the compressor reaches its maximum efficiency at the load and speed for which it was designed. The loss in efficiency due to speed regulation, however, is much less than that due to cylinder bypass and clearance pockets.

Multiple compressors in parallel.--As was just pointed out, the maximum capacity of a reciprocating compressor is delivered when the

^{2/} When a liquid is raised to the boiling point corresponding to the pressure on the liquid, the resulting gas is said to be "saturated." If this gas is removed from the liquid and is heated to undergo an increase in temperature without an increase in pressure, it is said to be "superheated." The degree of superheat is the difference between the temperature of the gas at its saturated temperature and its temperature after being superheated.

compressor is operated at its designed load; therefore, in a plant where the load varies appreciably, the most economical arrangement is to have two or more compressors connected in parallel. Each compressor will then operate at its designed capacity, and as the load varies, the compressors will start up or shut off by means of automatic switches. This method requires a higher initial investment, a greater number of parts in the system, and a larger space. The increase in efficiency, however, will in time offset the higher initial cost. Thus, in spite of the initial cost, the use of multiple compressors in parallel is the method most widely employed for obtaining capacity regulation.

Compressor size and method of drive.—Reciprocating compressors are available in sizes of 1/4 hp. to over 350 hp. They are suitable for pumping efficient refrigerants such as ammonia, methyl chloride, carbon dioxide, Freon 12, and Freon 22. If the compressor is of 100 hp. or less, the compressor, the driving motor, the condenser, and the receiver usually form an integral unit. If compressors of over 100 hp. are used, the condenser and receiver are located in the machinery space adjacent to the compressors. The most common method of driving reciprocating compressors is by means of an alternating-current induction motor. The compressor is, however, readily adaptable for drive by means of a direct-current motor, steam engine, diesel engine, or gasoline engine. Because of its adaptability for these various drives, it has a very wide range of use in refrigeration applications. Its high efficiency, low initial cost, low maintenance cost, ruggedness, and compactness are reasons for its wide use.

Selection of a reciprocating compressor.—There are many factors that should be considered when a reciprocating compressor is selected for a particular application. The following is a list of some of the more important of these factors:

1. The horsepower and tonnage rating at the evaporator temperatures required.
2. The amount of floor space taken up by the compressor and drive.
3. The size of the component equipment such as condenser and receiver.
4. The ability of the compressor to operate efficiently at variable loads.
5. The initial cost, operating cost, and over-all efficiency.
6. The advantages and disadvantages of the refrigerant to be used.
7. The ruggedness, durability, and ability to operate automatically.

Centrifugal Compressors

The centrifugal compressor is well suited for high-tonnage and low-temperature requirements. This type of compressor is made in sizes of 100- to 3,000-tons capacity. The refrigerants most widely used in it are Freon 11 and Freon 113.

The centrifugal compressor (figure 6) resembles, in principle, a multiple-stage, centrifugal water pump consisting of 2 to 4 impellers in series, with a stationary set of diffuser plates for each impeller. The total pressure produced is the sum of the pressures produced by the individual impellers. The pressure produced by the centrifugal compressor is also related to the molecular weight of the refrigerant, those refrigerants having a high molecular weight being the most suitable for use. The compressor rotates at speeds from 3,500 to 4,000 r.p.m. for units of 1,000- to 2,000-tons capacity, and from 7,000 to 8,000 r.p.m. for units of 100- to 200-tons capacity. Power may be provided by electric motors equipped with gear-type speed increasers or by a steam turbine. The capacity of the machine can be efficiently controlled by varying the speed of the drive or by using a suction damper that controls the flow of gas to the compressor.

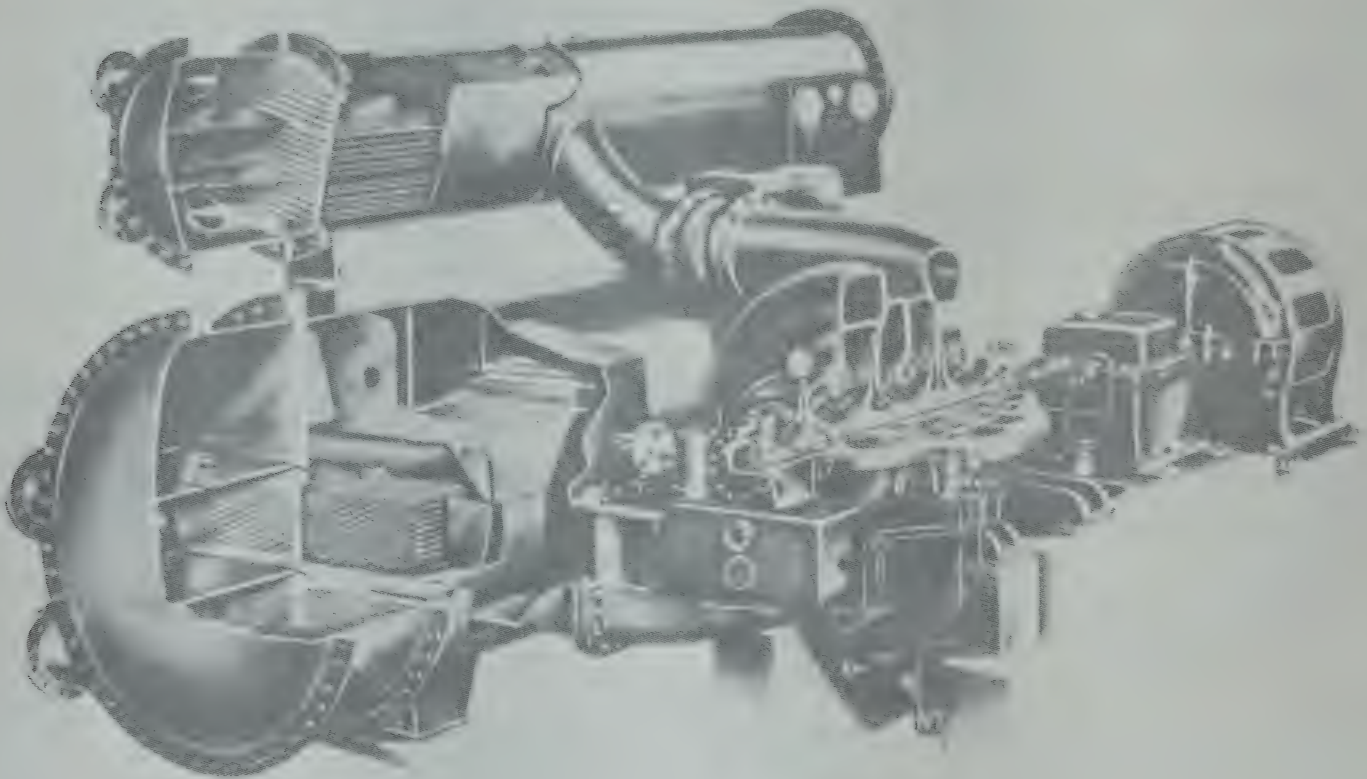


Figure 6.--A centrifugal compressor with condenser and brine cooler.
(Photo courtesy of Worthington Corporation)

Because of the large volume of gas required to produce the necessary refrigeration effect, an indirect system with a heat exchanger must be employed. The heat exchanger is of the flooded type, with the Freon 11 flowing around the tubes and the brine circulating through the tubes. The condenser, brine cooler, interstage liquid cooler, compressor, and drive are usually located on a common base plate. This arrangement results in less heat losses and makes a more compact unit.

Commercial use of the centrifugal machine has largely been limited to large refrigerator ships and to air conditioning.

Rotary Compressors

The rotary compressor has recently been adapted for use as a booster or low-stage compressor in many cold storage and freezing plants. The machine is well suited for this application because of its high efficiency in handling large volumes of gas at low pressure.

In a two-stage system, the difference between the suction and discharge pressure of the low-stage compressor is relatively small (5 to 30 pounds). If this pressure difference decreases to about 5 to 10 pounds, difficulty in valve operation of a reciprocating compressor might be experienced, whereas the operation of a rotary compressor, which has no valves, will not be affected. However, the rotary compressor is not suitable for use as a high-stage compressor because of the limited allowable pressure difference across the machine.

The rotary compressor consists essentially of a cylinder within which is located a rotor fitted with blades. The gas--usually Freon 12 or ammonia--enters the compressor through a series of suction ports and is compressed by the rotating blades and forced out of a discharge port located in the casing. In many machines, a secondary "coolant" is circulated through a jacket to prevent freeze up of the cylinder due to the low suction-temperature encountered.

Condenser

The function of the condenser is to cool the gaseous refrigerant after it leaves the compressor, thereby changing it to a liquid. The two principal types of condensers are the water-cooled type and the air-cooled type.

The water-cooled condenser consists of a shell with tubes running longitudinally through it. Salt water or fresh water circulating through these tubes cools the refrigerant, which surrounds the outside of the tubes. The water, in flowing through the tubes, makes from one to four passes, depending on the particular design of the equipment.

The air-cooled condenser (figure 7) is similar to a radiator in an automobile in that it consists of rows of finned tubing. Two fans--one

attached to the drive pulley on the compressor and the other to the drive pulley on the motor—draw the air in from the surrounding atmosphere and over the finned coils, thereby cooling the gaseous refrigerant circulating through the finned coils.

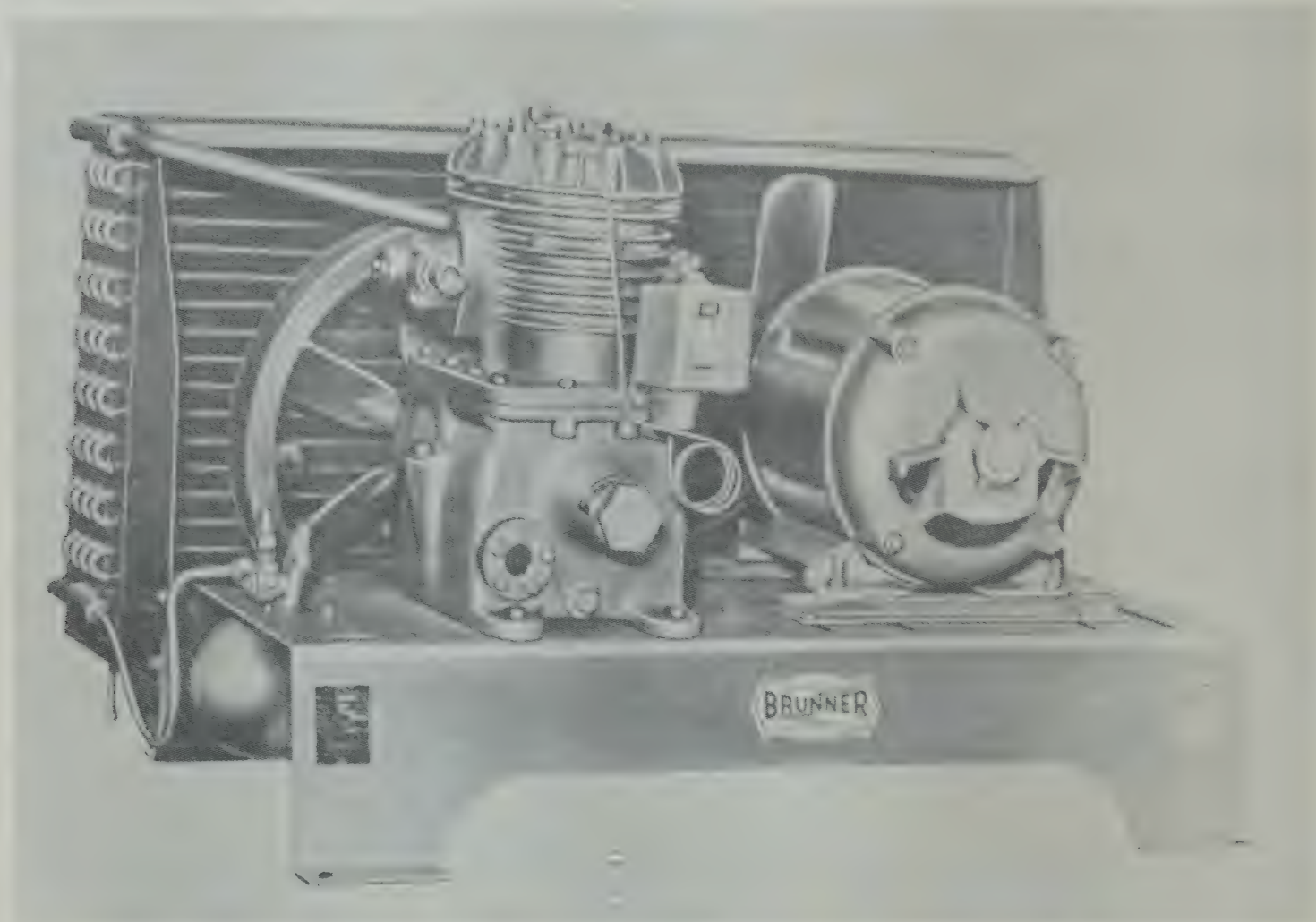


Figure 7.—A 3-hp Freon 12 compressor with an air-cooled condenser.
(Photo courtesy of Brunner Manufacturing Company)

Of the two types of condensers mentioned above, the water-cooled type is used the more extensively. This is because of its adaptability for both large and small loads. The air-cooled condenser is used largely with small refrigerating compressors, from 1/4 hp. to 3 hp. It has found wide usage in small Freon installations and in refrigerated railroad cars and trucks.

Receiver

The receiver is a cylindrical vessel used to store additional refrigerant. It is located between the condenser and the expansion valve (figure 1). In providing a storage place for the refrigerant, the receiver performs the following two functions:

1. It furnishes additional refrigerant in the event of leakage.
2. It provides a storage place for the refrigerant when the system is shut down for maintenance.

Expansion valve

The function of the expansion valve is to control the flow of refrigerant through the evaporator. This valve makes it possible to obtain a high heat transfer within the evaporator and also prevents liquid refrigerant from entering the compressor. The first expansion valves were operated manually and had to be adjusted whenever the load varied. The hand-operated expansion valves have now been replaced by automatic-type expansion valves that are of the thermostatic type, the constant-pressure type, or the float-operated type.

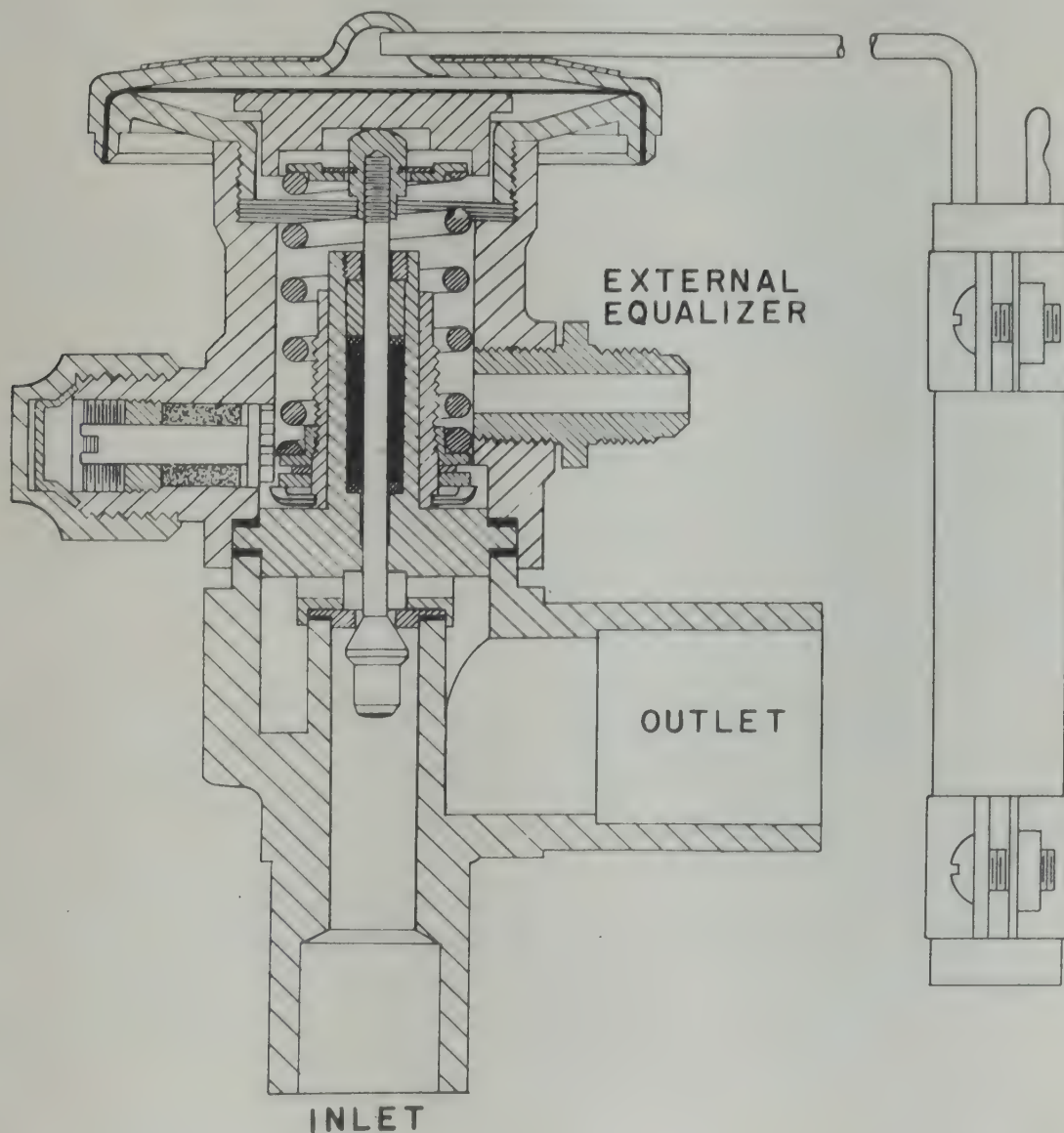


Figure 8.—Cross-sectional view of a single-outlet thermo-expansion valve for Freon 12. (Photo courtesy of Alco Valve Company)

In the thermostatic type (figure 8), the valve opening is controlled by the temperature of the gas leaving the evaporator. In the constant-pressure type, the valve opening is controlled by the evaporator pressure. In the float-operated type, the valve opening is controlled by the level of liquid refrigerant in the evaporator. The float-operated type is used only on flooded-evaporator systems, whereas the thermostatic and the constant-pressure types are used on both flooded and dry-expansion systems. (For a description of flooded and dry-expansion systems, see "Evaporators.")

Evaporator

The design of a particular evaporator depends upon the specific cooling application involved, rather than upon the nature of the refrigeration system employed, such as the compression or absorption system. Therefore, a detailed discussion of evaporators will be given later in this section. At this point, it will suffice to say that the evaporator is primarily a piece of heat-transfer equipment, using refrigerant as a cooling medium, thereby cooling air, water, brine, or foodstuffs.

Auxiliary equipment and controls

In addition to the basic equipment required in the compression system, auxiliary equipment and controls are necessary to insure satisfactory operation.

Auxiliary Equipment

The auxiliary equipment required consists of the following: (1) oil separator, (2) drier, (3) sight glass, and (4) heat exchanger. The following discussion will be concerned with the functions of these pieces of equipment in regard to the compression system.

Oil separator.--A small amount of oil mixes with the refrigerant during the compression cycle. If this oil is allowed to circulate through the system, sticking of the expansion valves and a drop in operating capacity will result.

The oil separator consists of a cylindrical tank equipped with baffles and a sight glass, located in the hot-gas discharge line between the compressor and condenser. The oil contained in the refrigerant-discharge gas, after being mechanically trapped in the oil separator, flows back to the compressor crankcase.

Drier.--The drier is used to absorb the small amounts of moisture that may infiltrate into the system and is located in the liquid line between the receiver and the expansion valve. Commercial driers consist of a tubular vessel containing a removable cartridge made of

a moisture-absorbing material—such as silica gel, activated alumina, anhydrous calcium sulfate, or calcium oxide.

Sight glass.—The sight glass is located in the liquid discharge line, usually after the drier, and it enables the operator to observe when there is an insufficient amount of refrigerant in the system or when the refrigerant flow stops as the result of a frozen expansion valve or of other causes.

Heat exchanger.—The heat exchanger is located between the evaporator and the low side of the compressor. The mixture of liquid and vapor leaving the evaporator is superheated when passing through the heat exchanger, by the liquid refrigerant flowing in coils within the heat exchanger. The liquid refrigerant, after being chilled in the heat exchanger, then enters the expansion valve. The precooling of the liquid refrigerant by the superheating of the compression suction gas increases the capacity output of the compressor considerably. Heat exchangers should be used in all commercial applications where the evaporator temperature is below 20° F.

Controls

To obtain continuous automatic operation of the compression system, certain controls are necessary. The ones generally used consist of a thermostat, a solenoid valve, a low-pressure switch, and a high-pressure switch. (For ultra-low temperature applications, other controls are used, which, however, will not be treated here.)

The thermostat (figure 9) is essentially an electric switch that is opened or closed by a thermo bulb filled with mercury. Thermostats are located in the cold-storage room and are available for the control of temperatures from 40° to -100° F. The electric switch in the thermostat is connected in series with the electric coil in the solenoid valve. The solenoid valve is located in the liquid refrigerant line after the receiver and just before the expansion valve. The low- and high-pressure switches are on the compressor. The low-pressure

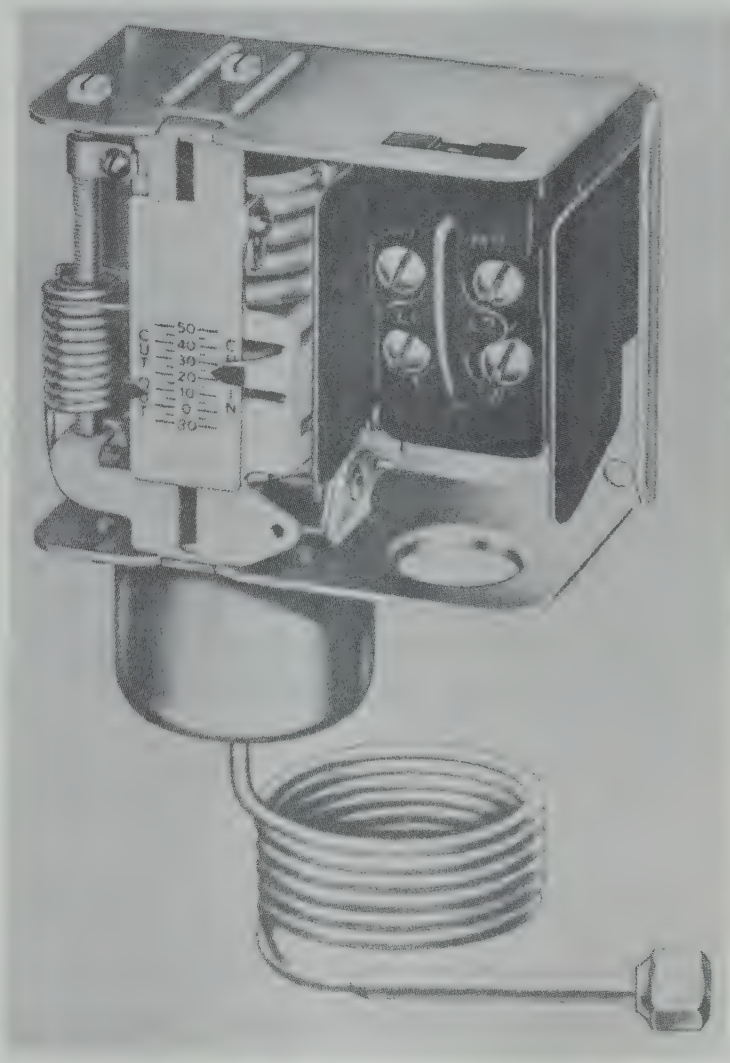


Figure 9.—A low-temperature thermostat. (Photo courtesy of Penn Controls, Inc.)

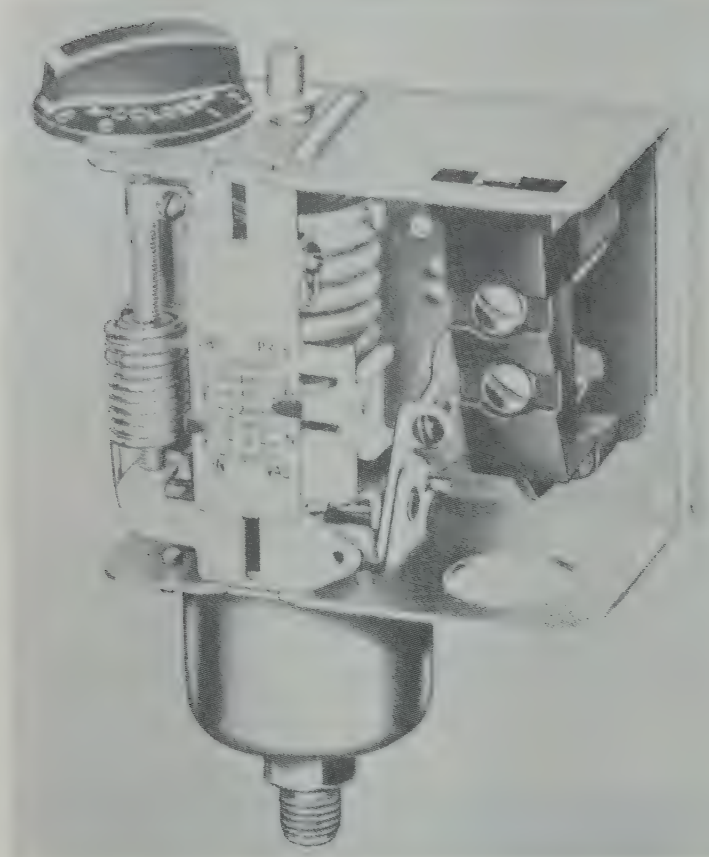


Figure 10.--A low-pressure switch.
(Photo courtesy of Penn Controls,
Inc.)

switch (figure 10) shuts off the power to the compressor when the suction pressure reaches the predetermined lower limit, and starts it up again when the suction pressure rises to the predetermined upper limit. The high-pressure switch shuts off the compressor when the discharge pressure exceeds the normal operating pressure, thereby preventing damage to the machinery.

The operation cycle of these controls is as follows: When the cold-storage room reaches its operating temperature, the switch in the thermostat opens, causing the solenoid valve to close, thereby stopping the flow of refrigerant to the evaporator. The compressor then pumps the vapor out of the evaporator, thereby reducing the suction pressure. When the suction pressure reaches that of the setting on the low-pressure switch,

the switch opens and shuts off the power to the compressor. When the temperature in the cold-storage room rises $2\frac{1}{2}^{\circ}$ F., the thermostatic switch closes, energizing the coil in the solenoid valve, causing it to open. The open solenoid valve then admits refrigerant to the evaporator, causing a rise in the suction pressure. When the suction pressure reaches that of the setting on the low-pressure switch, the compressor starts up again.

Most refrigeration compressor systems are designed so that the compressor will actually operate for about 16 hours a day--or about two-thirds of the time.

ABSORPTION SYSTEM

The first absorption machine was invented in 1860 by Ferdinand Carre, in France. It gained considerable prominence from 1860 to the early 1900's, when the ammonia compression machine became widely accepted. Work was then concentrated on the advancement of the compression machine until the late 1930's, when companies began to introduce absorption machines, ranging from 25- to 3,600-tons capacity, for industrial use. The following discussion will deal with the principle of operation and the equipment used in the modern absorption system.

Principle of Operation

Ammonia is the only economically suitable refrigerant for use in the absorption system. The principle of the absorption system is based on the absorption of ammonia vapor by water at cooling-water temperature and the release of ammonia vapor when the water is heated. The following is a description of the operation:

Liquid anhydrous ammonia is stored under a pressure of approximately 160 p.s.i.g. in an ammonia receiver (figure 11). From the receiver, the ammonia is fed through an expansion valve into the

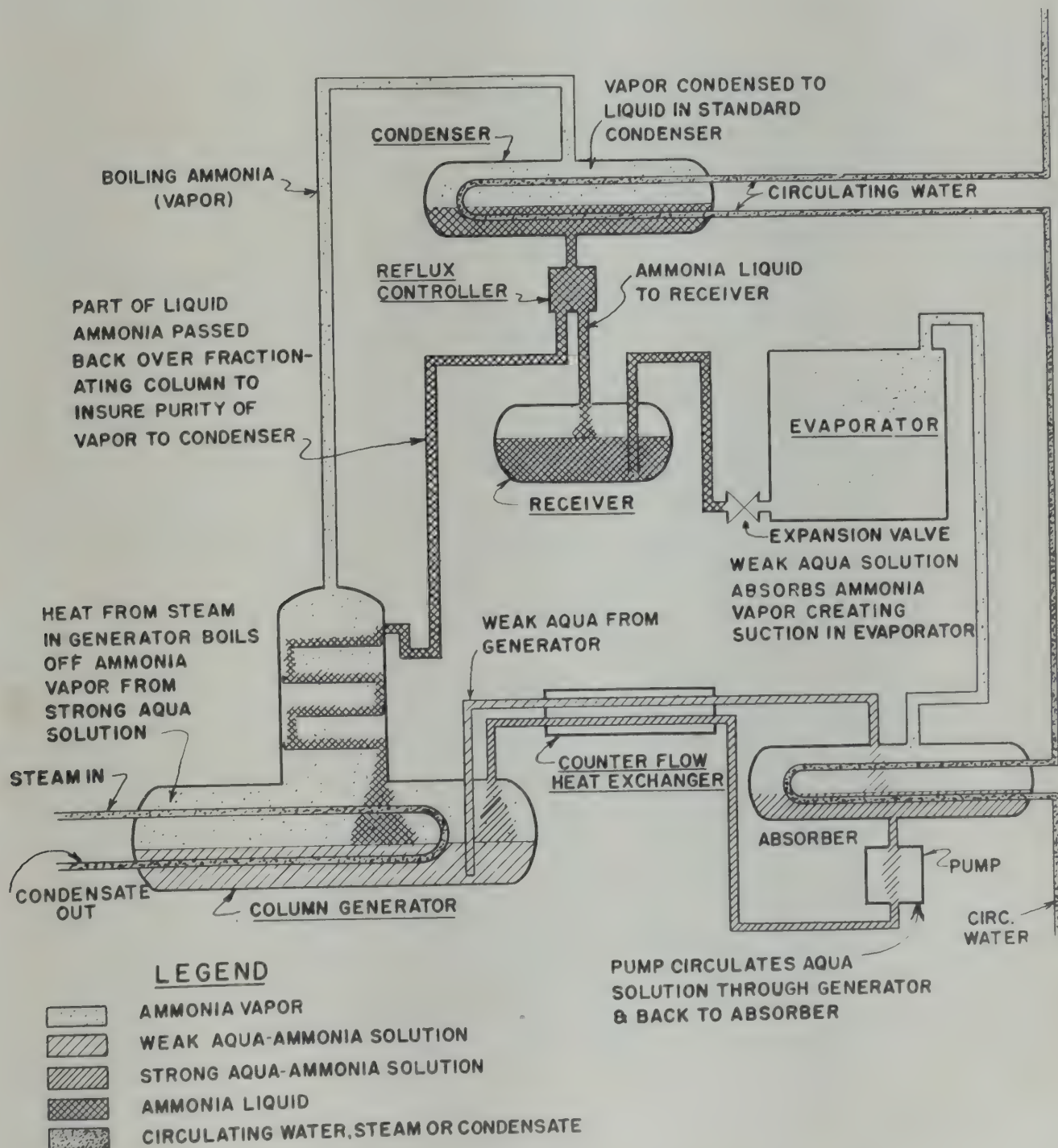


Figure 11.--Flow diagram of the absorption system. (Photo courtesy of Thermofreeze Company)

evaporating coils, if used in a direct system, or into a flooded or direct expansion-type brine cooler, if used in an indirect system (see Evaporators). The ammonia vapor that is formed by the extraction of heat in the evaporating coils flows from the evaporator into the absorber at a pressure corresponding to that of the refrigerant at the evaporator temperature. The absorber is similar to a shell-and-tube-type condenser, with water at temperatures of 50° to 70° F. circulating through the tubes. In the absorber, the ammonia vapor mixes with the "weak liquor", which flows from the generator through a heat exchanger to the absorber. The mixture of ammonia and water formed in the absorber is referred to as "strong liquor." The strong liquor is then pumped from the absorber through a heat exchanger to the generator by an aqua-ammonia pump. The heat exchanger serves two purposes: (1) to cool the weak liquor and (2) to add heat to the strong liquor. The generator consists of a cylindrical shell with heating coils immersed in the strong-liquor solution (aqua ammonia). Steam flows through the heating coils, adding heat to the strong liquor and causing a mixture of ammonia and water vapor to rise into the distilling column. As this mixture rises through the column, it passes through a series of baffles and is cooled by liquid ammonia that is admitted from the condenser to the top of the column. This liquid ammonia condenses the water contained in the mixture of ammonia and water vapor, causing it to return to the generator, where it mixes with the strong liquor. The weak liquor formed in the generator when the ammonia is driven off then flows to the absorber. The ammonia vapor leaving the distilling column goes to the condenser, where it is condensed to a liquid. The liquid ammonia then flows from the condenser to the receiver. A continuous supply of liquid ammonia also flows from the condenser through a reflux meter to the distilling column. The portion of ammonia entering the receiver now goes to the evaporator, and the cycle begins again.

To operate the absorption system efficiently, a perfect balance must be obtained at all times: that is, there must be the proper amount of weak and strong liquor flowing for each pound of ammonia going into the evaporator, the proper amount of cooling water flowing to the condenser and absorber, and the proper amount of steam flowing to the generator. The absorption machine is best suited for large, steady loads because of the difficulty in maintaining a perfect balance at variable loads.

Equipment

The equipment contained in the absorption system consists of a receiver, expansion valve, evaporator, absorber, aqua pump, generator, distillation column, reflux meter, and condenser. The function and design of the receiver, expansion valve, evaporator, and condenser are the same as that described in the compression system. The following discussion will deal with the functions and general design features of the equipment that is peculiar to the absorption system--the absorber, aqua pump, heat exchanger, generator, distillation column, and reflux meter.

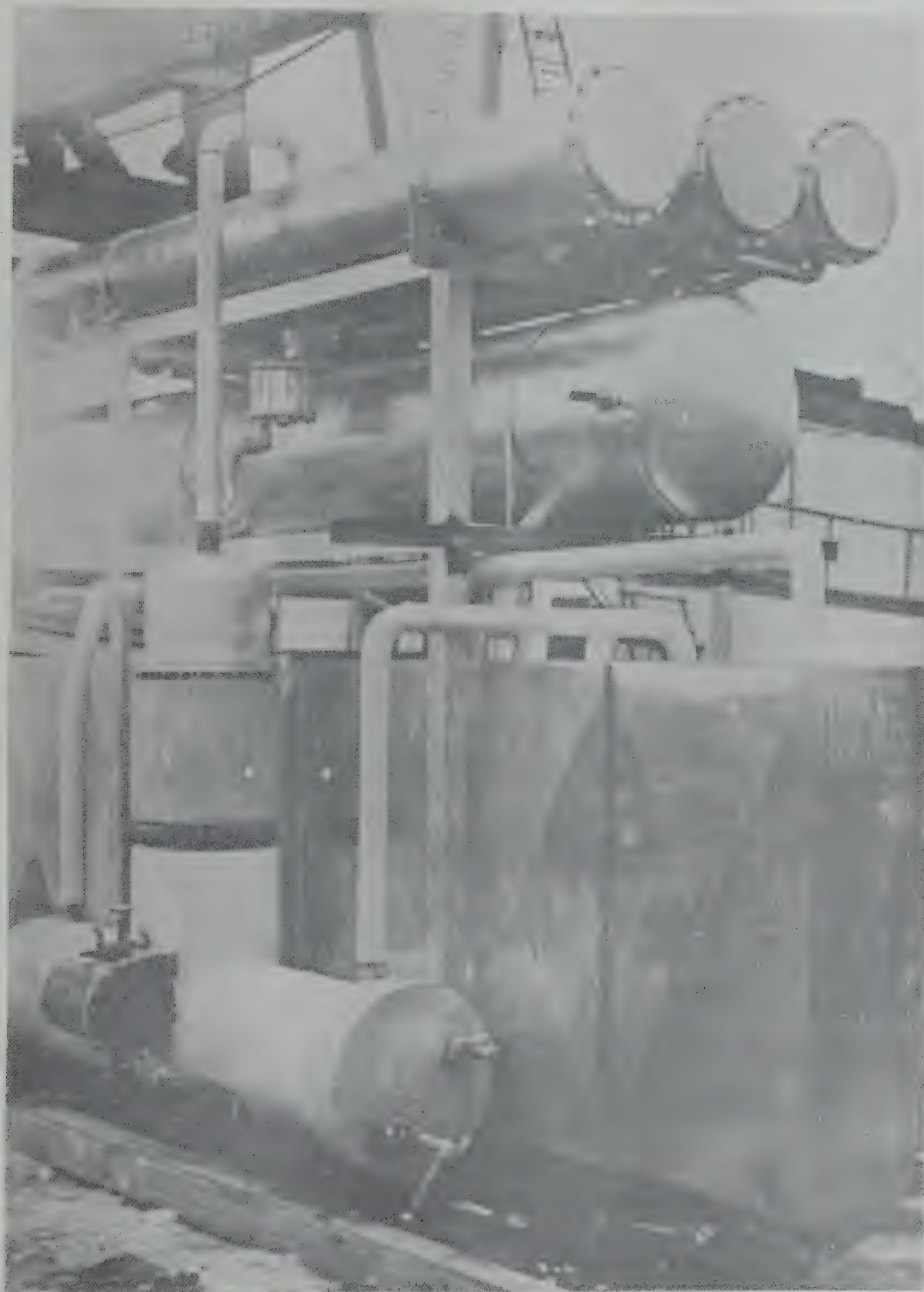


Figure 12.--View of an absorption refrigeration unit. (Photo courtesy of Thermofreeze Company)

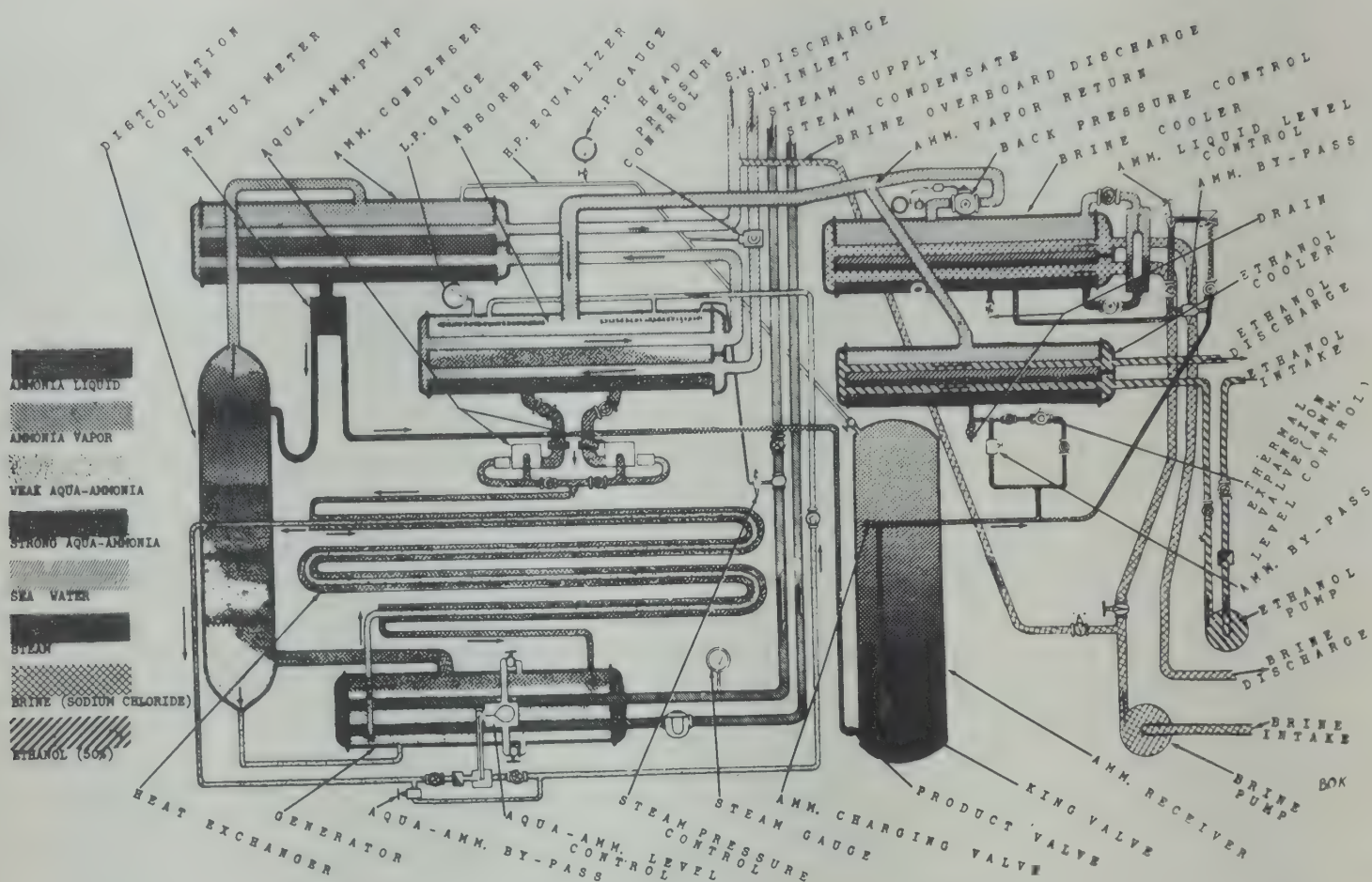


Figure 13.—Diagrammatic view of an absorption system as installed on a fishing vessel. (Drawn by Boris Knake, Fish and Wildlife Service)

Absorber

The absorber is similar to a shell-and-tube-type condenser. Fresh or salt water is circulated within the tubes making from 1 to 4 passes, depending on the specific design. The ammonia vapor from the evaporator mixes with weak liquor, which flows around the outside of the tubes within the vessel. The resulting solution, or strong liquor, is then pumped to the generator by the aqua pump. The fresh or salt water used as a cooling medium takes away the waste heat from the weak liquor, so that the proper absorption of ammonia from the evaporator will take place.

Aqua pump

The aqua pump can be of the reciprocating or rotary type. One reciprocating type in use is hermetically sealed, thereby preventing any ammonia leakage by the drive shaft. The aqua pump is used to pump the strong liquor from the absorber through the heat exchanger into the evaporator. It has been found that to obtain maximum performance, the aqua pump should pump approximately 8 pounds of strong liquor for each

pound of ammonia passing through the evaporator. Some pumps have a variable-speed drive so that the speed of the pump can be reduced when operating at small loads and increased when operating at large loads. Either a direct- or alternating-current motor is used for driving the pump.

Heat exchanger

The function of the heat exchanger is to heat the strong liquor before it enters the generator, and at the same time, cool the weak liquor before it enters the absorber. This exchange of heat permits a substantial saving in steam input to the generator and also saves on the amount of cooling water required in the absorber.

The heat exchanger is usually of the counterflow type, which is merely an insulated pipe with a smaller pipe running inside the larger one. The weak aqua flows in one direction through one pipe, while the strong aqua flows in the opposite direction through the other. This type of heat exchanger is used because of its high rate of heat transfer.

Generator

The generator is a heat exchanger, usually of the shell-and-tube type. Steam flowing through the tubes at a pressure of 15 to 25 p.s.i.g. heats the strong liquor surrounding the tubes, causing the ammonia to vaporize and rise into the distillation column at a pressure of 120 to 160 p.s.i.g. The amount of steam supplied to the generator varies with the operating load.

Distillation column or analyzer

The distillation column--sometimes referred to as an analyzer--consists of a chamber containing, at spaced levels, a series of plates with small valves through which pass the vapors leaving the generator. From the condenser, cold liquid ammonia enters the top of the distillation column and drops in countercurrent flow to the vapors leaving the generator. In so doing, the cold liquid ammonia--owing to its affinity for water--strips the water vapor from the hot ammonia vapor. The result is that approximately 98-percent-pure ammonia vapor leaves the column and flows to the condenser.

Reflux meter

The reflux meter consists of an orifice in a pipe connecting the bottom of the condenser to the top of the distillation column. This orifice permits a steady flow of liquid ammonia to the distillation column, thereby enabling it to function properly.

COMPARISON BETWEEN THE ABSORPTION AND COMPRESSION SYSTEMS

The selection of an absorption or a compression machine depends largely on the type of service desired and on the conditions that prevail where the machine is to be used. The following summary of the advantages of the absorption system over the compression system gives an indication of the types of applications for which the absorption system should be considered.

1. The only moving part of the absorption system is the aqua pump; therefore, the operation is relatively quiet and subject to little mechanical wear.

2. Waste or exhaust steam can economically be utilized to supply the energy necessary to operate the absorption system.

3. For low-temperature applications, the absorption machine can operate with little decrease in capacity, whereas the capacity of a compression machine decreases greatly at low evaporator temperatures.

4. At reduced loads, the absorption unit is almost as efficient as at full capacity.

5. Liquid refrigerant leaving the evaporator will slightly unbalance the absorption system; whereas in a compression system, this liquid refrigerant will cause serious damage to the compressor.

6. The absorption system will operate at capacities of well over 1,000 tons, whereas the largest single-compression unit does not exceed 1,000 tons.

7. When used in large plants, the absorption equipment can be located outside the cold-storage building.

The following summary of the advantages of the compression system over the absorption system gives an indication of the types of applications for which the compression system should be considered:

1. At high evaporating temperatures, a compression machine will operate more efficiently than will an absorption machine.

2. For evaporator temperatures of 0° F. and above, the initial cost of the compression machine is cheaper.

3. The compression machine requires less maintenance because of the type of equipment used.

4. The compression machine is positive acting, with the performance depending on the compressor, condenser, and evaporator; whereas the

performance of the absorption machine depends on the proper proportioning of all its parts, the condition of each piece of equipment, and the skill of the operating engineer.

5. The compression machine can economically use refrigerants such as ammonia, carbon dioxide, Freon 12, Freon 22, and methyl chloride; whereas the absorption machine is limited to the use of ammonia, which has many undesirable properties.

6. The compression machine takes up considerably less space.

7. The compression machine is manufactured in sizes from 1/4-ton to 1,000-tons capacity, whereas there are very few companies that make absorption units smaller than 100-tons capacity.

8. The compression machine can be driven by an electric motor, diesel engine, gasoline engine, or steam engine; whereas only steam can be used with the absorption machine.

9. The compression machine has a wide range of applicability that has been proven hundreds of thousands of times in such installations as refrigerated vessels, sharp freezers, blast freezers, and plate freezers.

EVAPORATORS

The evaporator is designed to effect an efficient heat transfer between the cooling medium and the material to be cooled. Evaporators have been designed to cool many materials; however, this discussion will be concerned only with the principal uses of the evaporator in relation to the cold storage and freezing of fishery products.

Classification

There are two general types of evaporators: the direct-expansion evaporator, and the indirect-expansion evaporator.

In the direct-expansion type, the refrigerant itself, expanding through the evaporator, absorbs the heat from the material to be cooled, whereas in the indirect-expansion type, refrigerated brine, circulating through the "evaporator" tubes, absorbs the heat from the material to be cooled.

The following is a discussion of these two types of evaporators, with emphasis on their relative merits.

Direct-expansion evaporators

In the direct-expansion evaporator, the refrigerant is used as a cooling medium to cool air, water, brine, or food product. An example

of a direct-expansion evaporator is a cold-storage room with pipe coils attached to the ceiling. The refrigerant flowing through the pipes absorbs the heat from the air, which is circulated around the outside of the pipe coils by natural convection currents. Thus, the air in the room is cooled as a result of the mixture of liquid and gaseous refrigerant in the pipes changing to a vapor.

There are two general types of systems employed in direct-expansion evaporators: the dry-expansion system, and the flooded system.

In the so-called dry-expansion system, the evaporator coils are only partially filled with refrigerant. In the flooded system, a cylindrical vessel, which is referred to as an accumulator, is located at the end of the evaporator coils. The accumulator is maintained with a sufficient amount of refrigerant to keep the evaporator coils flooded with "boiling" refrigerant at all times. The top of the accumulator is connected to the compressor suction, in the compression system, or to the absorber, in the absorption system.

The flooded system is used in preference to the dry-expansion system in large commercial installations, where excessive pressure drops are incurred because of the length of the evaporator coils. The dry-expansion system is used for small evaporators, where a large pressure drop is not encountered. The rate of heat transfer is higher in the flooded system than in the dry-expansion system.

Indirect-expansion evaporators

In the indirect-expansion evaporator, a refrigerated brine solution is pumped through the so-called evaporator coils, thereby cooling the surrounding atmosphere or product. Calcium-chloride brine is generally used in a closed system, where the brine is circulated within the evaporator coils on which the fish are frozen, while a sodium-chloride brine is used in an open system, where the fish are frozen by direct contact with the brine.

A brine cooler (the true evaporator) is used to refrigerate the brine solution. There are two types of commercially available brine coolers: the direct-expansion brine cooler, and the flooded brine cooler.

In the direct-expansion brine cooler, the brine is cooled by expansion of the refrigerant through a series of pipe coils located within the shell of the cooler. The brine is circulated around the outside of the pipe coils by a brine pump. The baffles in the cooler are arranged in such a manner that the brine can make from 1 to 6 passes.

In the flooded-type brine cooler, the brine is circulated through a series of tubes located within a cylindrical vessel. The brine usually

makes from 1 to 4 passes. The exact number of passes varies with the specific type of cooler design. The brine is cooled by "boiling" liquid refrigerant surrounding the outside of the tubes. The refrigerant is maintained at a level of approximately $2/3$ the diameter of the cooler, by a float-type expansion valve.

Application

The specific design of the evaporator depends to a large extent on the types of application for which it is to be used. In the freezing of fishery products, we are concerned with only those evaporators designed for use in cold-storage plants and quick freezers. The following is a general description of some of the commercial evaporators used for the cold storage and freezing of fishery products.

Cold-storage rooms

There are three commercial types of evaporators used in cold-storage plants. The first two types consist of pipe coils or finned pipe coils suspended from the ceiling of the room (figure 14). Refrigerant or

brine is circulated through the coils, thereby cooling the surrounding atmosphere to the proper temperature. The third type is a blower-type cooling unit. This evaporator consists of a housing that contains coils of finned pipe and one or more fans located so as to force the air in the room around the coils (figure 15). A refrigerant such as ammonia or Freon 12 is generally used as the cooling medium, but in some units, cold brine has also been used. A more detailed description of the commercial evaporators used in cold-storage plants is given in the section entitled "Cold Storage Design."

Quick freezers

Fishery products are frozen in evaporators referred to as sharp, plate, blast,



Figure 14.--Finned pipe coils in a cold-storage room. (Photo courtesy of York Corporation)

or immersion freezers. In the sharp, plate, or blast freezers, either a refrigerant or a brine solution can be used in the evaporator, whereas in the immersion freezer, a brine solution is generally used. These freezers are described in the section entitled "Refrigeration Requirements and Freezing Methods" (section 3).

Defrosting of Evaporators

The accumulation of frost on evaporator coil surfaces will result in a reduction of heat transfer between the refrigerant and the air or product being cooled. Defrosting has sometimes been accomplished by shutting off the flow of refrigerant to the evaporator and opening the cold-storage-room door, thereby admitting warm air to the inside of the room. This procedure is not recommended because of (1) the possibility of product thawing, (2) the large amount of time required, and (3) the excessive amount of moisture admitted. To remove frost accumulation from evaporators quickly and yet prevent the product from changing temperature, two types of defrosting systems have been developed: water defrosting, and hot-gas defrosting.

Water defrosting

Water defrosting is a cheap and efficient method for defrosting blower-type cooling units that produce evaporator temperatures from above freezing to -40° F. Defrosting is accomplished by circulating water at a temperature of about 50° F. through spray nozzles located above the evaporator coils. The nozzles should be in sufficient quantity to provide adequate water to defrost the coils completely in 5 to 10 minutes. At temperatures below 0° F., a flow of 3 gallons of water per minute per square foot of coil surface area is required for effective defrosting. When defrosting, the fan should be stopped, and the refrigerant supply to the coils should be closed off. To prevent the water from freezing, a suitable drain, with a trap located outside the refrigerated space, must be installed to carry off the water. Defrosting can be accomplished manually, or automatically by means of a suitable timing device and the proper arrangement of valves and piping.

Water defrosting is not suitable for use with coils having gravity circulation of air, since the spray-header system would be too extensive.



Figure 15.--Blower-type cooling units in a refrigerated room. (Photo courtesy of Blount Seafood Corporation)

Hot-gas defrosting

Hot-gas defrosting is accomplished by causing the hot gas discharged from the compressor to flow through the evaporator coils. If two or more evaporator coils are served by one compressor, the piping can be arranged so that the hot gas from the compressor discharge will flow through a first set of evaporator coils that are connected, in turn, to a second set of evaporator coils. The hot gas, in flowing through the first set of coils, provides the necessary heat for defrosting and, as a result, changes from a hot gas to a cold liquid. This liquid, in flowing through the second set of coils, absorbs heat from the medium surrounding them and, in so doing, changes back to a gas. On systems in which only one evaporator is used, an additional heat exchanger must be installed to prevent liquid refrigerant from entering the compressor. Hot-gas defrosting can be accomplished manually or automatically by means of a suitable timing device and the proper arrangement of valves and piping.

REFRIGERANTS

A gas, to be suitable for use as an efficient refrigerant, must have a low boiling temperature and a high latent heat of vaporization^{3/} at atmospheric pressure, in addition to many other properties. All other factors being equal, a lower boiling point and a higher latent heat of vaporization will result in a greater absorption of heat per pound of refrigerant flowing through the evaporator. However, good thermodynamic properties do not necessarily determine the ideal refrigerant. Such a refrigerant, in addition to having good thermodynamic properties, must be nonexplosive, nontoxic, noninflammable, noncorrosive, nonirritating, noninjurious to foods, suitable for mechanical application, practically odorless, easily obtainable, inexpensive, efficient, and economical to use.

Many types of refrigerants have been tried since the inception of the mechanical refrigeration system. In recent years, new refrigerants closely resembling the ideal refrigerant have been developed. The refrigerants used in commercial refrigeration installations today are ammonia, Freon 12, carbon dioxide, methyl chloride, Freon 11, and Freon 22. The following discussion will be concerned with the advantages and disadvantages that should be considered in the selection of these refrigerants for use in a commercial refrigeration plant.

Ammonia

Ammonia is a very economical and efficient refrigerant because of its low boiling point and high latent heat of vaporization at atmospheric pressure. It is used extensively in large commercial and

^{3/} The latent heat of vaporization, expressed in British thermal units (B.t.u.'s), is the heat necessary to cause 1 pound of refrigerant to change from a liquid to a gas at its boiling temperature.

industrial refrigeration plants. In small- and medium-sized commercial plants, ammonia is being replaced to a great extent by Freon 12 and Freon 22 because of their many advantageous physical properties.

Advantages of Ammonia

Ammonia (1) has excellent thermodynamic properties, (2) is a very efficient refrigerant, (3) is neutral to iron and steel, (4) is ideally suited for use in compression and absorption systems, and (5) has low initial cost.

Disadvantages of Ammonia

Ammonia (1) requires high pressure, (2) attacks most alloys, (3) diminishes in efficiency with overheating, (4) is highly toxic, and (5) adversely affects food, water, and plant life.

Freon 12 (Dichlorodifluoromethane)

Freon 12 is an economical and efficient refrigerant. It is not, however, as efficient as ammonia, because of its higher boiling point and its lower latent heat of vaporization at atmospheric pressure. The boiling temperature of ammonia at atmospheric pressure is -28° F., and its latent heat of vaporization is 589 B.t.u. per pound. In comparison, the boiling temperature of Freon 12 at atmospheric pressure is -21° F., and its latent heat of vaporization is about 72 B.t.u. per pound.

Freon 12 is used in lieu of ammonia in many small commercial refrigeration plants because of its nontoxic properties and the compactness of the condensing unit required. It is as near a perfect refrigerant as is presently obtainable. The following are the advantages and disadvantages of Freon 12 that should be considered in its use in a commercial refrigeration plant:

Advantages of Freon 12

Freon 12 (1) has good thermodynamic properties, (2) has moderate operating pressures, (3) is noncorrosive, (4) is nontoxic, (5) is nonflammable, (6) is nonexplosive, (7) is practically odorless, and (8) does not affect food or plant life.

Disadvantages of Freon 12

Freon 12 (1) requires that care be taken to remove all air and moisture, as otherwise, corrosion and freezing of the expansion valve might result; (2) has high solvent action on rubber; (3) is not as economical to use as is ammonia; and (4) has a high initial cost.

Carbon Dioxide

Carbon dioxide is used extensively in refrigeration systems in large industrial plants. It operates under extremely high pressures, requiring close attention. The following are the advantages and disadvantages that should be considered in the use of carbon dioxide in a commercial refrigeration plant:

Advantages of Carbon Dioxide

Carbon dioxide is (1) cheap, (2) easily obtainable, (3) non-inflammable, (4) nonpoisonous, (5) noncorrosive, (6) odorless, (7) requires small compressor and small piping, and (8) does not affect food or plant life.

Disadvantages of Carbon Dioxide

Carbon dioxide (1) operates under extremely high pressure, which may cause leakage at joints and stuffing boxes; (2) requires high motor power; and (3) requires a large continuous supply of cold condensing water for efficient operation.

Methyl Chloride

Methyl chloride is extensively used in commercial reciprocating and rotary compressors up to 25 hp. The following are the advantages and disadvantages that should be considered in the use of methyl chloride in a commercial plant:

Advantages of Methyl Chloride

Methyl chloride (1) can be used at low operating pressures; (2) does not affect metals; (3) can readily be used in air-cooled condensers; and (4) is odorless, but can be tainted with a warning agent to give notification of leaks.

Disadvantages of Methyl Chloride

Methyl chloride (1) is inflammable; (2) dissolves lubricants; (3) absorbs moisture from the air, resulting in hindering or stopping of the action of the expansion valve; (4) adversely affects food and plant life; (5) is highly toxic; and (6) is explosive.

Freon 11 (Trichloromonofluoromethane)

The physical properties of Freon 11 are similar to those of Freon 12. Freon 11 is used in large commercial centrifugal compressors where a large volume of refrigerant is delivered and a refrigerant of high molecular weight is required.

Freon 22 (Monochlorodifluoromethane)

The physical properties of Freon 22 are also similar to those of Freon 12. Freon 22, however, has a lower boiling temperature at atmospheric pressure, and it operates at higher discharge pressures than does Freon 12. It is used largely in place of Freon 12 for low-temperature applications.

BIBLIOGRAPHY

AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

1955. Air Conditioning Refrigerating Data Book, Design Volume, Ninth edition. American Society of Refrigerating Engineers, New York.

JORDAN, RICHARD C., and PRIESTER, GAYLE B.

1948. Refrigeration and Air Conditioning. Prentice-Hall, Inc., New York.

OSBORNE, A.

1943. Modern Marine Engineers Manual, volume II. Cornell Maritime Press, New York.

SHARPE, N.

1949. Refrigeration Principals and Practices. McGraw-Hill, New York.

SIEBEL, J. E.

1911. Mechanical Refrigeration and Engineering, Eighth edition. Nickerson and Collins Company, Chicago, Illinois.

SPARKS, N. R.

1938. Theory of Mechanical Refrigeration. McGraw-Hill, New York.

TAYLOR, HARDEN F.

1927. Refrigeration of fish. U. S. Bureau of Fisheries, Document No. 1016.

TRESSLER, DONALD K., and EVERS, CLIFFORD F.

1947. The Freezing Preservation of Foods, Second edition. Avi Publishing Company, Inc., New York.

VENEMANN, HENRY G.

1946. Refrigeration Theory and Applications, Second edition,
Nickerson and Collins Company, Chicago, Illinois.

VOORHEES, G. T.

1924. The Absorption Refrigeration Machine. Nickerson and
Collins Company, Chicago, Illinois.

WACHTER, G. J.

1955. Refrigeration compressors in frozen food industry. Frosted
Food Field, vol. XXI, No. 2, August, pp. 36-38.

WILE, D. D.

1953. Water defrost of blower coils. Refrigerating Engineering,
vol. 61, No. 3, March, pp. 266-268.

WRIGHT, I. K.

1936. Commercial Refrigeration. Nickerson and Collins Company,
Chicago, Illinois.

SECTION 3

REFRIGERATION REQUIREMENTS AND FREEZING METHODS

By Joseph W. Slavin, Refrigeration Engineer *

TABLE OF CONTENTS

	Page
Refrigeration requirements	113
Package and product factors in freezing	113
Packaging	113
Thickness of package	113
Insulating effect of package	114
Surface area of package	114
Thickness of product	114
Temperature of product	115
Effect of higher product temperature on refrigeration capacity	116
Effect of higher product temperature on time required to freeze product	117
Refrigeration-system factors in freezing	117
Refrigeration capacity	117
Temperature of the cooling medium	120
Method of heat transfer between product and cooling medium	121
Sharp freezer	121
Multiplate freezer	122
Blast freezer	122
Immersion freezer	122
Freezing methods	122
Sharp freezers	123
Conventional-type sharp freezer	124
Continuous-conveyor-type sharp freezer	125
Multiplate freezers	127
Batch-type multiplate freezer	127
Continuous-type multiplate freezer	132
Blast freezers	134
Blast rooms	134
Tunnel-type freezer	134
Immersion freezers	137
An immersion freezer designed to freeze New England groundfish aboard a fishing vessel	138
An immersion freezer designed for the freezing of shrimp aboard a fishing vessel	140

* Fishery Technological Laboratory, East Boston 28, Massachusetts

	Page
An immersion freezer designed to freeze tuna aboard a fishing vessel	142
Bibliography	144

ILLUSTRATIONS

Figure 1.—Freezing packaged fish fillets in a sharp freezer	123
Figure 2.—Freezing halibut in a conventional-type sharp freezer	124
Figure 3.—A sharp freezer with a continuous conveyor . . .	126
Figure 4.—A multiplate compression freezer	127
Figure 5.—Freezing 1-inch-thick packaged fish fillets in a multiplate compression freezer	128
Figure 6.—Freezing 2-inch-thick packaged fish fillets in a multiplate compression freezer	129
Figure 7.—Freezing 2½-inch-thick packaged fish fillets in a multiplate compression freezer	130
Figure 8.—Freezing 1½-inch-thick (10-ounce) packages of fish sticks in a multiplate compression freezer	131
Figure 9.—A continuous multiplate compression freezer . .	133
Figure 10.—A tunnel-type blast freezer	135
Figure 11.—Freezing packaged fish fillets and fish sticks in a tunnel-type blast freezer	136
Figure 12.—Cutaway view of the <u>Delaware</u> showing brine- freezing tanks and fish storage bins	138
Figure 13.—Fresh shrimp entering the freezing tank aboard the shrimp trawler <u>Prince Charming</u> . . .	141

TABLES

Table 1.—Freezing time for whole round cod and haddock, of various thicknesses, in sodium-chloride brine at 10° and 0° F.	140
---	-----

This section will discuss (1) the refrigeration requirements and (2) the methods used in the freezing of fish.

REFRIGERATION REQUIREMENTS

Numerous factors control the freezing of fishery products. These factors may be divided into two classifications: (A) those that are controlled by the product and that should be considered in the preparation and packaging of a product for freezing and (B) those that are controlled by the refrigeration system and that should be considered in the installation and application of a refrigeration system for freezing the fishery product.

Package and Product Factors in Freezing

In the production of a quick-frozen product, such factors as (a) packaging, (b) thickness of product, and (c) temperature of product prior to freezing are important.

Packaging

Sufficient study is not always given to the type and size of package for a particular type of product. It is quite common for a contract to be signed for the delivery of a large amount of packages, even though a definite method of freezing has not been decided on.

To freeze packaged fishery products quickly and efficiently, thought should be given to the thickness of the package, the insulating effect of the package, and the surface area of the package. The following is a brief discussion of these items and how they effect the freezing of packaged fishery products.

Thickness of package.—The optimum thickness of package for a particular product is that size which will enable the production of a high-quality product at a minimum production cost. The use of a thin package will result in (1) faster product freezing, (2) lower freezing-power costs, (3) higher handling costs, and (4) higher packaging-material costs; the use of a thick package will result in (1) slower product freezing, (2) higher freezing-power costs, (3) lower handling costs, and (4) lower packaging-material costs.

Tests conducted at the U. S. Fish and Wildlife Service laboratory, East Boston, Massachusetts, showed that, by freezing packaged fish fillets in the thinner packages, (1) a faster freezing rate and (2) a larger volume of frozen-product output is obtained (Slavin 1955). These tests also showed that less electrical energy is required to freeze packaged fish fillets in the thinner packages than in the thicker ones.

It is very important that the top of the product comes in contact with the package, thereby eliminating a dead-air space, which would

increase the freezing time and refrigeration costs considerably.

Insulating effect of package.—A packaging material with a low moisture-vapor permeability is used in the manufacture of most packages for fishery products. This material protects the product while it is in cold storage by preventing excessive dehydration. However, the material also has an insulating effect, which increases the freezing time and the freezing costs. The rate of heat transfer through the packaging material is inversely proportional to its thickness. Therefore, the ideal packaging material is thin enough to produce the maximum possible freezing rate, and yet thick enough to withstand the abuse that the package will encounter.

Surface area of package.—For two packaged products of the same weight, the package with the larger surface area will freeze the faster (see "Thickness of package"). The surface area of a package is also important in the freezing of the product, because of its relation to the size of the freezer. Therefore, the package surface area should be so determined that there will not be any unused product space in the freezer after it has been loaded to its maximum capacity. This determination of proper surface area is very important in the operation of a multiplate compression freezer.

Thickness of product

The greater the thickness of a product in relation to the surface area in contact with the cooling medium, the greater is the time required for the center to freeze. The time required to freeze, however, is not directly proportional to the product thickness, as might be assumed. Tests conducted by the U. S. Fish and Wildlife Service laboratory, East Boston, Massachusetts, indicated that the time required to freeze packaged fish fillets in a plate freezer is approximately directly proportional to the square of the package thickness, in accordance with the following equation:

$$\frac{t_x}{t} = \frac{d_x^2}{d^2} \quad \text{or} \quad t_x = \frac{td^2}{d_x^2}$$

where t_x is the time required to freeze a package of thickness d_x , if t is the time required to freeze a package of thickness d .

Thus, if it takes 180 minutes (t) to freeze packaged fish fillets 2 inches thick (d), it will take about 281 minutes (t_x) to freeze packaged fillets $2\frac{1}{2}$ inches thick (d_x), since

$$t_x = \frac{(180)(2.5)^2}{2^2}$$

$$t_x = 281 \text{ minutes}$$

The actual freezing time, in experimental tests, varied from 260 to 280 minutes, depending on the air space in the package and the plate temperature.

To apply the foregoing formula, the user should keep all other factors the same--such as plate temperature, packaging material, and air space in the package: the thickness of the packaged product should be the only variable. Increased air space within the package or a higher plate temperature will increase the freezing time considerably.

Temperature of Product

The heat contained within a product is commonly given in British thermal units (B.t.u.), 1 B.t.u. being the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit. The amount of heat, expressed in B.t.u., required to raise the temperature of 1 pound of a material 1 degree Fahrenheit, is called the specific heat of the material.

Since the specific heat of water and of ice differ and since the flesh of fish is composed of about 80 percent water, fish have two different specific heats: the one, before freezing, and the other, after freezing^{1/}. The specific heat, expressed in B.t.u. per pound of most fishery products before freezing is 0.8; the specific heat after freezing is 0.4.

The freezing process involves the removal of two types of heat: sensible heat and latent heat. Sensible heat involves a change of product temperature without a change of state (as when the temperature of water is lowered from 40° F. to 32° F.), whereas latent heat involves a change of product state without a change of temperature (as when water freezes to ice at 32° F. or when ice melts to water at 32° F.). The latent heat is largely removed from most fishery products between the temperatures of 29° and 27.5° F. The latent heat of most fishery products has been calculated to be approximately 115 B.t.u. per pound. The formula given below is used to determine the amount of heat that must be extracted to freeze a certain quantity of fish.

If:

- Q = total heat to be extracted from product (B.t.u.).
- T₁ = temperature of product prior to freezing (degrees Fahrenheit).
- T₂ = temperature at which the latent heat is removed from product (degrees Fahrenheit) ^{2/}.

^{1/} This simplified concept of a constant heat above and below freezing, although not in complete accord with experimental observations, is sufficiently accurate for most freezing calculations.

^{2/} Fish does not freeze at a definite temperature, but rather over a range of temperatures (see Fishery Leaflet 429, section 1). However, T₂ can usually be taken as 28° F., for most calculations.

T_3 = final temperature of frozen product (degrees Fahrenheit).
 c = specific heat of product prior to freezing (B.t.u. per pound per degree Fahrenheit).
 c_i = specific heat of product, after freezing (B.t.u. per pound per degree Fahrenheit).
 L = latent heat of product (B.t.u. per pound).
 W = weight of product being frozen (pounds).

Then:

$$\begin{aligned}
 Q &= W(T_1 - T_2)c + WL + W(T_2 - T_3)c_i \\
 &= W[(T_1 - T_2)c + L + (T_2 - T_3)c_i]
 \end{aligned}$$

The following problem and solution show how this formula is applied.

Problem 1:

Determine how much heat, expressed as B.t.u., must be extracted to lower the temperature of 1,000 pounds of fish from 40° to 0° F.

Solution to problem 1:

$$\begin{aligned}
 Q &= W[(T_1 - T_2)c + L + (T_2 - T_3)c_i] \\
 &= 1,000 [(40-28)0.8 + 115 + (28-0)(0.4)] \\
 &= 136,000 \text{ B.t.u. (rounded off)}
 \end{aligned}$$

$$W = 1,000 \text{ lbs.}$$

$$T_1 = 40^\circ \text{ F.}$$

$$T_2 = 28^\circ \text{ F.}$$

$$T_3 = 0^\circ \text{ F.}$$

$$c = 0.8 \text{ B.t.u./lb./}^\circ\text{F.}$$

$$c_i = 0.4 \text{ B.t.u./lb./}^\circ\text{F.}$$

$$L = 115 \text{ B.t.u./lb.}$$

Effect of higher product temperature on refrigeration capacity.--

The following problem and its solution show the effect of a high product temperature on refrigeration capacity.

Problem 2:

Assuming that 136,000 B.t.u. must be extracted to lower the temperature of 1,000 pounds of fish from 40° to 0° F., how much more heat would have to be extracted if the initial temperature had been 60° instead of 40° F.?

Solution to problem 2:

$$\begin{aligned}Q_{12} &= W(T_1 - T_2)c \\&= (1,000)(60-40)(0.8) \\&= 16,000 \text{ B.t.u.} \\&\quad \frac{(16,000)(100)}{136,000} = 11.8\%\end{aligned}$$

$$\begin{aligned}W &= 1,000 \text{ lbs.} \\T_1 &= 60^\circ \text{ F.} \\T_2 &= 40^\circ \text{ F.} \\c &= 0.8 \text{ B.t.u./lb./}^\circ\text{F.}\end{aligned}$$

This calculation indicates that by prechilling the fish from 60° to 40° F. in a chill room or in ice immediately prior to freezing, 11.8 percent less refrigeration capacity will be required.

Effect of higher product temperature on time required to freeze product.--The freezing time of a particular product is determined by a combination of many factors in addition to the product temperature, such as packaging, refrigeration capacity, method of heat transfer between product and cooling medium, and temperature of cooling medium. These factors are more or less interrelated, and it would be very difficult to state exactly how much any one factor would affect the freezing time. However, with other factors being equal, the product with a higher initial temperature will take longer to freeze. This fact can be illustrated by referring to the solution of problems 1 and 2. Assuming that the refrigeration machine used to freeze the fish in problem 1 was designed to lower the temperature of 1,000 pounds of 1-inch-thick packaged fillets of fish from 40° F. to 0° F. in 1 hour (the required refrigeration capacity is 136,000 B.t.u. per hour), it would take at least 1 hour and 7 minutes to freeze the fish in problem 2, which had an initial temperature of 60° F.

Thus, both the refrigeration capacity requirements and freezing time can be decreased by precooling the product before freezing.

Refrigeration-System Factors in Freezing

The factors that are controlled by the refrigeration system and that affect the freezing time and cost of freezing are (1) the refrigeration capacity, (2) the temperature of the cooling medium, and (3) the method of heat transfer between product and cooling medium. As these factors are interrelated, a composite study of the exact effect of each one on the freezing of fish would be lengthy. Therefore, the following discussion will deal with only the general effects of these factors.

Refrigeration Capacity

The capacity of a refrigeration system is expressed in tons of refrigeration. One ton of refrigeration, given in B.t.u., is equal to the heat that must be removed in freezing 2,000 pounds of water at 32°F.

to ice at 32° F., in a 24-hour period. Expressed in B.t.u., 1 ton of refrigeration is equal to the removal of 288,000 B.t.u. per 24 hours (2,000 x 144), 12,000 B.t.u. per hour, or 200 B.t.u. per minute.

A refrigeration system designed to freeze a certain quantity of fish must have sufficient capacity, in tons of refrigeration, to equal the heat in B.t.u. that must be withdrawn from the product within a predetermined time, to cool it from its temperature prior to freezing to a temperature suitable for preservation (about 0° F.).

For example: A 1-pound package of 1-inch-thick packaged fillets can be cooled from 40° to 0° F. in a period of 1 hour in a plate freezer with refrigerant at a temperature of -24° F. flowing through the plates. To cool 1,000 1-pound packages of this product within a period of 1 hour, the refrigeration system must have a heat-withdrawal capacity equal to 1,000 times the B.t.u. required to cool the single 1-pound package.

A producer who, by experimentation, finds that a particular product will freeze within a certain period of time with a refrigerant at a certain temperature flowing through the evaporator can readily determine the refrigeration capacity requirement in B.t.u. per hour necessary to freeze any predetermined amount of this product, by the formula given below, where:

- q = heat per unit of time to be extracted from product (B.t.u. per hour).
- t = time required to freeze product (hours).
- T₁ = original temperature of product prior to freezing (degrees Fahrenheit).
- T₂ = temperature at which the latent heat is removed from the product (degrees Fahrenheit).
- T₃ = final temperature of frozen product (degrees Fahrenheit).
- c = specific heat of product prior to freezing (B.t.u. per pound per degree Fahrenheit).
- c_i = specific heat of product, after freezing (B.t.u. per pound per degree Fahrenheit).
- L = latent heat of product (B.t.u. per pound).
- W = weight of product to be frozen (pounds).

$$q = \frac{1}{t} [W(T_1 - T_2)c + WL + W(T_2 - T_3)c_i]$$

or

$$q = \frac{W}{t} [(T_1 - T_2)c + L + (T_2 - T_3)c_i]$$

The following two problems illustrate how to determine the necessary refrigeration capacity requirement in B.t.u. per hour if the freezing

time, the product temperature before and after freezing, the temperature of the refrigerant in the evaporator, and the pounds of fish to be frozen are known:

Problem 1:

Experimental data show that a 1-inch-thick 1-pound package of fish fillets can be cooled from 40° to 0° F. in a period of 1 hour with refrigerant at a temperature of -24° F. circulating through the plates in a plate freezer. What is the capacity requirement of the refrigeration system in B.t.u. per hour necessary to freeze 1,000 pounds of this product?

Solution to problem 1:

$$q = \frac{W}{t} [(T_1 - T_2)c + L + (T_2 - T_3)c_i]$$

$$= \frac{1,000}{1} [(40-28)0.8 + 115 + (28-0)0.4]$$

$$= 136,000 \text{ B.t.u./hr.}$$

$$q = \text{B.t.u./hr.}$$

$$t = 1 \text{ hour}$$

$$T_1 = 40^\circ \text{ F.}$$

$$T_2 = 28^\circ \text{ F.}$$

$$T_3 = 0^\circ \text{ F.}$$

$$c = 0.8 \text{ B.t.u./lb./}^\circ\text{F.}$$

$$c_i = 0.4 \text{ B.t.u./lb./}^\circ\text{F.}$$

$$L = 115 \text{ B.t.u./lb.}$$

$$W = 1,000 \text{ lbs.}$$

Problem 2:

Experimental data show that a 2-inch-thick 10-pound package of fish fillets can be cooled from 40° to 0° F. in 3 hours with refrigerant at a temperature of -24° F. circulating through the plates in a plate freezer. What is the capacity requirement of the refrigeration system in B.t.u. per hour necessary to freeze 1,000 pounds of this product?

Solution to problem 2:

$$q = \frac{W}{t} [(T_1 - T_2)c + L + (T_2 - T_3)c_i]$$

$$= \frac{1,000}{3} [(40-28)0.8 + 115 + (28-0)0.4]$$

$$= 45,300 \text{ B.t.u./hr.}$$

q	= B.t.u./hr.	T_3	= 0° F.
t	= 3 hours	c	= 0.8 B.t.u./lb./°F.
W	= 1,000 lbs.	c_i	= 0.4 B.t.u./lb./°F.
T_1	= 40° F.	L	= 115 B.t.u./lb.
T_2	= 28° F.		

In addition to the refrigeration capacity requirement necessary for product freezing, as expressed in problems 1 and 2, additional refrigeration capacity is necessary to compensate for wall-heat gain, air changes, and miscellaneous heat gains. For the calculation of these additional heat gains, see section 1 of this leaflet.

The capacity of a refrigeration system to be used in product freezing is equal to the product-freezing requirement in B.t.u. per hour plus the additional heat gains mentioned above. To select a suitable compression or absorption system for freezing a predetermined amount of fish within a certain period of time, the refrigeration-capacity requirement in B.t.u. per hour at the required evaporator temperature must be known.

Temperature of the Cooling Medium

The rate of heat transfer between a particular product and the cooling medium is proportional to the difference between the temperature of the product and that of the cooling medium. Therefore a lower cooling-medium temperature will result in removal of the heat from the product at a faster rate, thereby decreasing the product-freezing time. The actual decrease in product-freezing time depends on the particular type of product and the freezing method employed.

To produce a lower cooling-medium temperature, the refrigeration machine must operate at a lower suction pressure, resulting in increased compressor horsepower per ton of refrigeration produced. As the cooling-medium temperature becomes progressively lower, the ratio of compressor horsepower to tons of refrigeration produced increases considerably, resulting in higher operating costs.

As mentioned above, a low cooling-medium temperature results in (1) faster freezing and (2) increased refrigeration costs. Therefore, to freeze a product quickly and economically, a proper balance is necessary between the cooling-medium temperature, the freezing rate, and the cost of refrigeration per pound of product frozen. In the selection of a suitable cooling-medium temperature, the type of product to be frozen and the specific design features of the freezer must also be given the utmost consideration. In planning an installation to obtain fast product freezing economically, a refrigeration engineer should be consulted.

Method of Heat Transfer between Product and Cooling Medium

To obtain rapid product freezing, a high rate of heat transfer ^{3/} must exist between the product being cooled and the cooling medium. In addition, the size of the evaporator and the available refrigeration capacity must be adequate so as to maintain the cooling medium at its proper temperature.

The four principal methods of freezing fish are (1) placing the product on pipe-coil shelves that have either brine or refrigerant flowing through the pipes, as in a sharp freezer, (2) placing the product between two refrigerated plates, as in a multiplate freezer, (3) circulating cold air around the product, as in a blast freezer, or (4) immersing the product in a cold brine solution, as in an immersion freezer.

If, in these four principal methods of freezing, it were possible to keep all other factors such as packaging, thickness of product, temperature of product, and the temperature of the cooling medium constant, the rate of freezing would depend on the ability of the cooling medium to withdraw the necessary heat out of the product. The ability of a particular cooling medium, when cooled to a given temperature, to absorb the heat from the product is largely dependent on whether or not the medium is a good or poor conductor.

The following discussion will be concerned with the effect of the various cooling media used in sharp, multiplate, blast, and immersion freezers on the product-freezing time.

Sharp freezer.--In the sharp freezer, the fish to be frozen are placed on shelves comprised of pipe coils. In most cases, metal pans, large sections of galvanized sheet iron, or iron plates are placed on the coils, to hold the fish. A refrigerant such as ammonia, Freon 12, or cold brine is circulated through the pipes to provide the necessary refrigeration effect. The pans, sheets, or plates on which the fish are placed act as a conductor, thereby allowing the heat to flow between the points of contact of the fish and pan and the pan and pipes. The heat transfer between the refrigerant in the pipes and the fish, at the point of contact, is relatively high; however, the over-all heat-transfer rate is quite low because of the extensive surface area of the product that is not in contact with the pipes and that is cooled largely by the natural circulation of cold air within the freezer room. The result is slow and uneven product-freezing. If sufficient refrigeration capacity is available, fans can be used to circulate the cold air over the products, thereby increasing the freezing rate.

^{3/} The factors affecting heat transfer in an evaporator used to cool air or brine are too numerous to mention here. References listed at the end of the section give further information on this problem.

Multiplate freezer.--In the plate freezer, the upper and lower surfaces of the products are in contact with refrigerated aluminum plates. These plates act as a conductor that allows the heat to flow freely between the plates and the product. This ready transfer of heat results in fast and efficient freezing. However, if a positive contact between plates and product is not maintained, owing to air space in the package, or to other causes, slow and inefficient freezing will result. In freezing packages that are over 3 inches thick, the surface area not in contact with the refrigerated plates becomes appreciably large relative to the surface in contact with the plates, thereby greatly increasing the freezing time of the product. A large bulky product would be frozen more suitably in a blast freezer, where all exposed surfaces are scrubbed by circulating cold air.

Blast freezer.--In the blast freezer, air at a low temperature is circulated, by means of a fan, around the products to be frozen. To achieve rapid freezing, the air should be circulated over the products at velocities of over 500 feet per minute and should be of sufficient volume so that it does not rise more than 10 degrees in temperature while cooling the product. The velocity of the air circulating over the products can be controlled by varying the quantity of air delivered in cubic feet per minute and the air space between each row of products. A producer considering the construction of a blast freezer should consult a refrigeration engineer, to obtain a minimum product-freezing time economically.

Immersion freezer.--In brine freezing fish a very high heat transfer takes place between the fish and the brine. This is because the refrigerated brine, being a good conductor, is in contact with the exposed surface area of the entire fish. In order to obtain a high heat transfer rate between the fish and the brine, it is necessary that sufficient circulation of the brine be maintained so as to allow it to flow freely around the fish. This type of freezing is one of the quickest and most efficient methods of freezing round fish.

FREEZING METHODS

A concern that is establishing a plant for the freezing of fishery products should, in the selection of a freezer suitable for its requirements, consider the type of fishery product to be frozen, the amount of product to be frozen within a certain specified time, the cost of freezing, the handling costs, the equipment maintenance costs, and the quality and appearance of the frozen product.

These considerations have been reflected, to a large extent, in the design of the sharp, multiplate, blast, and immersion freezers that are used for the freezing of fishery products today. These freezers have been improved throughout the years, resulting in the development of conveyor-type sharp freezers, continuous multiplate freezers, and tunnel-type blast freezers.

The following will discuss the sharp, multiplate, blast, and immersion freezers, with particular emphasis on handling methods, product-freezing times, and relative merits.

Sharp Freezers

The sharp freezer was one of the first devices used for the freezing of fishery products. The freezer consists of a series of pipe-coil shelves, which are maintained at temperatures of -20° to -40° F. by refrigerant flowing through the pipes. The fish to be frozen are placed on these coils, in the round or in packages.

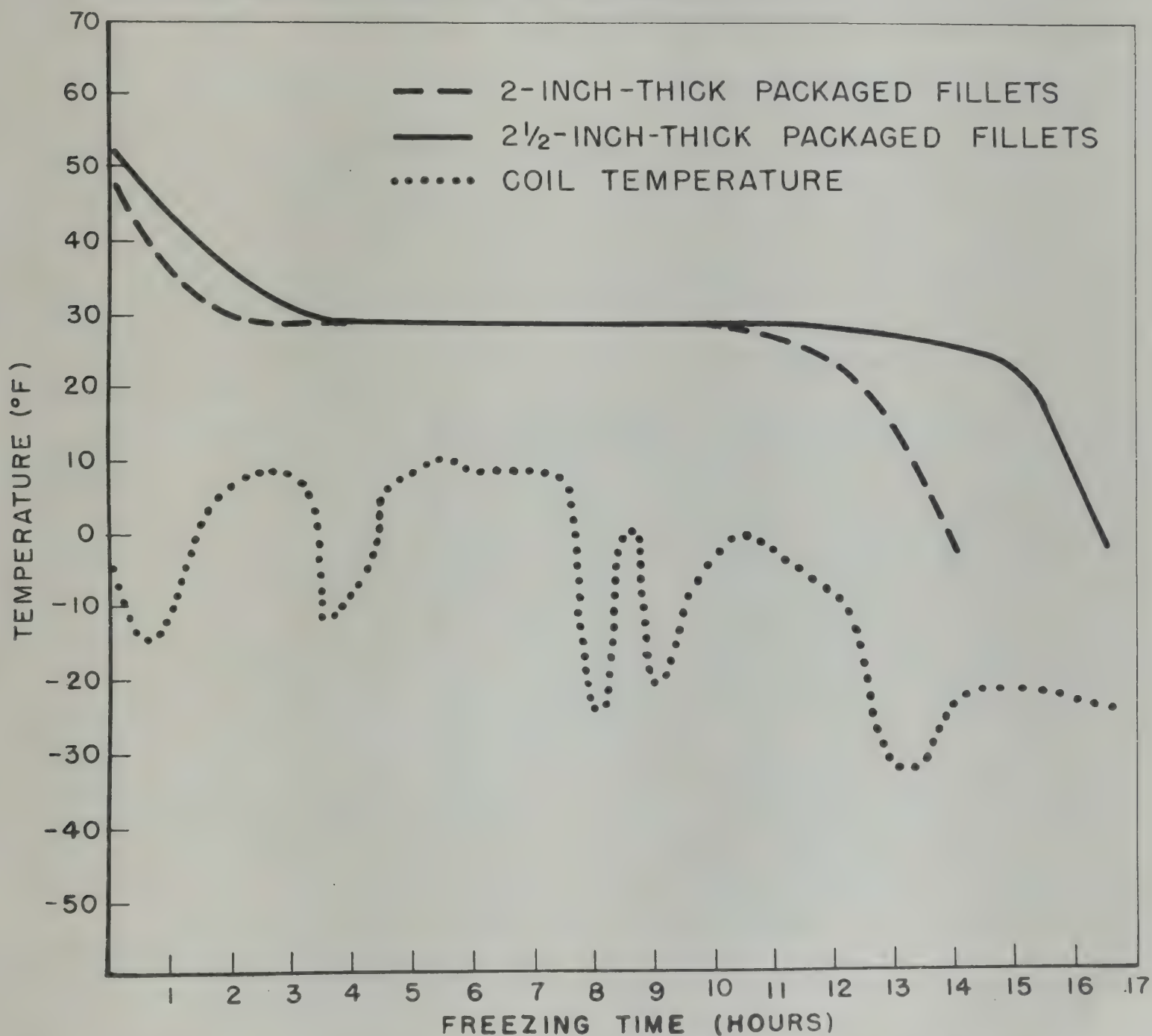


Figure 1.—Freezing packaged fish fillets in a sharp freezer.

Sharp freezers are referred to as either the conventional type or as the continuous-conveyor type.

In the conventional type, the products to be frozen are loaded onto skids. These skids are then moved into the freezer by a hand truck, and the products are unloaded from the skids and placed on the freezer shelves.

In the continuous-conveyor type, the products are conveyed from the processing room, by means of a continuous conveyor, into the freezer. The products are then removed from the conveyor belt by hand and placed on the freezer shelves.

The following is a description of typical commercial installations of these types of sharp freezers.

Conventional-Type Sharp Freezer

A large sharp freezer with a capacity of 40,000 pounds of 2½-inch-thick 10-pound packaged fish fillets consists of a room approximately 60 feet long, 24 feet wide, and 7 feet high located between two cold-storage rooms. The freezing is accomplished by means of two banks of coil shelves, 50 feet in length, located along each wall. There are 9 shelves in each bank of coils, with approximately 9 inches between each shelf. The coils consist of 1½-inch-diameter steel pipes, 18 coils to a shelf, with 5 inches between each coil. Ammonia is expanded through the



Figure 2.—Freezing halibut in a conventional-type sharp freezer.

coils to furnish the low coil-temperature necessary for freezing. In some sharp freezers, cold brine is circulated in the coils. This practice, however, is more costly, owing to (1) the lower heat-transfer rate and (2) the need for extra machinery and maintenance. Two or more low-velocity fans are used to provide adequate air circulation within the freezer. The coils are defrosted every 6 months, or when needed, by means of a hot-gas defrost.

The sharp freezer is suitable for freezing round fish in pans, or fish fillets packaged in 5- and 10-pound boxes. Packaged 5- and 10-pound boxes of fish fillets are received at the loading platform on skids from the processor. The skids are then moved into the freezer by a hand

truck, where the products are loaded on the pipe coils. Two men are used to unload each skid, and approximately two or three skids can be unloaded at once. After the freezer is loaded, the fans are started up, to provide the necessary air circulation. Four men can load or unload 40,000 pounds of packaged fish fillets in about 3 hours.

The time required to freeze packaged fish fillets in a sharp freezer is shown in figure 1.

The advantages of the sharp freezer are:

- (1) The cost of freezing is lower than with the blast or plate freezer.
- (2) The sharp freezer will give a fairly high output of frozen fish.
- (3) It has a low maintenance cost.

The disadvantages of the sharp freezer are:

- (1) It freezes products much slower than do blast, plate, or immersion freezers.
- (2) It requires considerable handling of products.
- (3) It requires that the coils be defrosted at least once every 6 months.
- (4) It requires that the 1-pound packages of fish fillets have weight on them to prevent them from bulging, owing to the expansion resulting from their being frozen.
- (5) The loading and unloading of the products results in coil frosting and increased freezing time.

Continuous-Conveyor-Type Sharp Freezer

This type of freezer is similar to the sharp freezer previously described, except for a continuous conveyor belt that is built into the freezer.

A freezer 110 feet long, 29 feet wide, and 10 feet high has capacity for 120,000 pounds of 10-pound boxes of packaged fish fillets. The freezing is accomplished by $1\frac{1}{4}$ -inch-diameter steel coils, which are flooded with ammonia. The coils are arranged in 4 banks: one bank is placed against each wall, and 2 banks are located in the center of the room. Each coil bank has 9 shelves (8 coils per shelf), with 7 inches between each shelf. Ammonia refrigeration is used to maintain the coils at temperatures of -10° to -20° F.



Figure 3.—A sharp freezer with a continuous conveyor. (Photo courtesy of Conveyor Specialty Company, Inc., and Cape Cod Cranberry Company)

A galvanized metal-mesh conveyor belt (12 inches wide and 335 feet long) runs from the processing table through an opening in the freezer wall into the freezer between the bank of the wall and center coils on one side of the freezer, around a 180-degree turn at the far end of the freezer, and back between the banks of wall coils and the center coils on the other side to the front of the freezer (figure 3). Another conveyor belt is connected to the previous one at the 180-degree turn. This conveyor runs from the back end of the freezer into an adjacent cold-storage room and out the end wall of the cold-storage room to a truck-loading platform.

The 10-pound commercial boxes of fish are placed on the conveyor belt in the processing room. The conveyor carries the fish into the freezer, where one man loads the boxes on the coil shelves. After the products are frozen, the fish are loaded onto the conveyor, which carries

them to the cold-storage room. The products for shipment are placed on a conveyor that carries them from the cold-storage room to the loading platform, where a portable conveyor is used to transport them into a refrigerated truck.

The advantages of this freezer over the conventional-type sharp freezer are (1) handling costs are reduced, (2) less defrosting is required, and (3) freezing time of products is but little affected by loading and unloading of the freezer.

Multiplate Freezers

The multiplate freezer lowers the product temperature by direct contact of the product with movable refrigerated aluminum plates. The first multiplate freezers were of the batch type and had to be loaded and unloaded by hand. However, recently, continuous multiplate freezers have been developed that can be loaded and unloaded automatically.

Batch-Type Multiplate Freezer

In the batch-type multiplate freezer, the freezing is accomplished by expanding a refrigerant through horizontal movable aluminum plates, which are stacked vertically within an insulated cabinet (figure 4). The plates are raised and lowered by a hydraulic-pressure system, thereby ensuring a positive contact between the plates and the packaged products during freezing. This type of freezer is available in capacities of from 360 to 2,400 pounds of 2-inch-thick 5-pound packaged fish fillets. In the small models, the compressor and accessory equipment are located under the freezing cabinet, whereas in the larger models, the refrigeration machinery is separate from the freezing cabinet. The refrigeration machinery is similar to

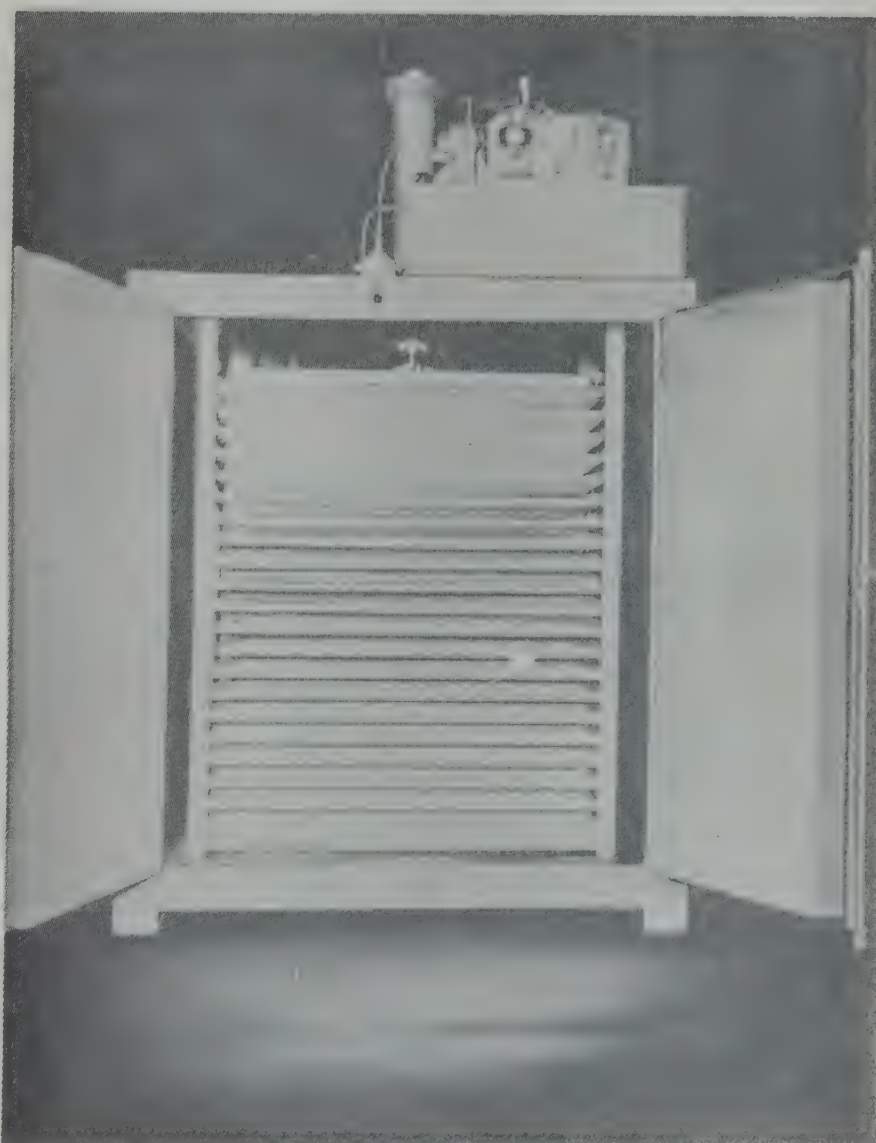


Figure 4.--A multiplate compression freezer.
(Photo courtesy of American Plate Freezer Corporation)

that of any compression system, consisting of a motor-driven compressor, condenser, receiver, expansion valve, and heat exchanger. The refrigerant inlet to the movable aluminum plates is connected to the expansion-valve outlet by means of flexible hoses. The outlet of the plates is connected to the compressor suction manifold also by flexible hoses.

Before the packaged products are placed in the freezer, the plates are cooled to about -15°F . These products are then laid on trays, which are placed on the movable aluminum freezer plates. Wooden spacers of the same length as the plates and of the same height as the packages are placed between each set of plates to prevent crushing of the packages. All the packages on the same plate must be of the same thickness, to ensure proper contact for freezing.

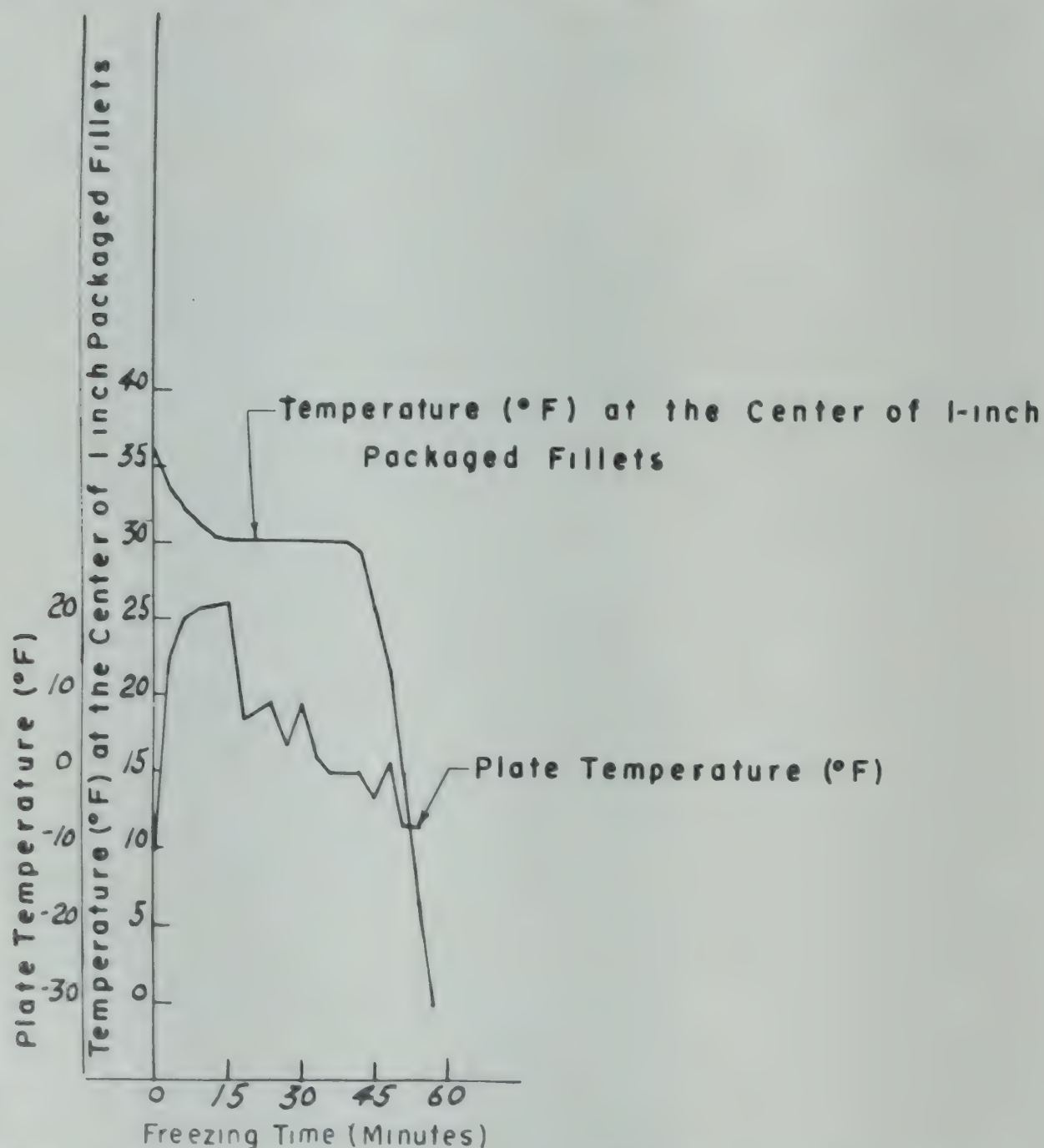


Figure 5.—Freezing 1-inch-thick packaged fish fillets in a multiplate compression freezer.

When the freezer is loaded, the cabinet doors are closed, and a lever is activated that supplies hydraulic pressure to the plates, causing them to move down on the spacers, thereby ensuring good contact between the packages and the plates. When the packaged products are frozen, the cabinet door is opened, the plates are raised, and the trays containing the packages are removed from the freezer.

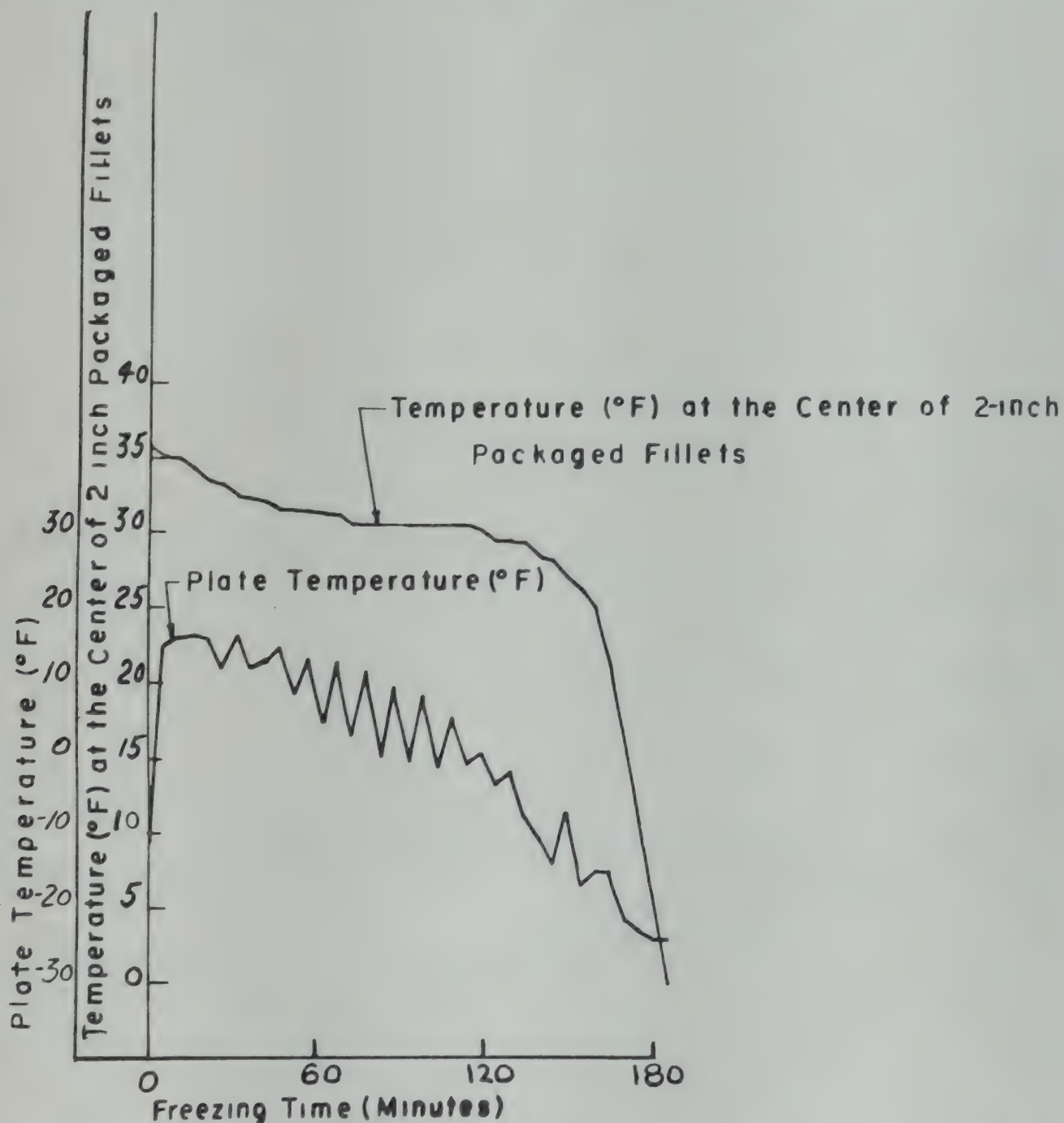


Figure 6.—Freezing 2-inch-thick packaged fish fillets in a multiplate compression freezer.

The multiplate freezer is very suitable for quick freezing fish fillets, packaged in 1-pound (1-inch-thick), 5-pound (2-inch-thick), and 10-pound (2½-inch-thick) commercial boxes. This freezer will also freeze packaged precooked fishery products very satisfactorily, producing a uniformly shaped package. Tests conducted at the Fish and Wildlife Service laboratory, East Boston, Massachusetts, (Slavin 1955) show that

the freezing time and energy required for freezing packaged precooked fish sticks is greater than that required for freezing packaged fish fillets, because of the slower rate of heat transfer due to the air space within the package. The freezing times required for fish fillets packaged in 1-pound (1-inch-thick), 2-pound (2-inch-thick), and 10-pound ($2\frac{1}{2}$ -inch-thick) commercial boxes, and breaded precooked fish sticks packaged in 10-ounce ($1\frac{1}{2}$ -inch thick) commercial boxes are shown in figures 5, 6, 7, and 8, respectively.

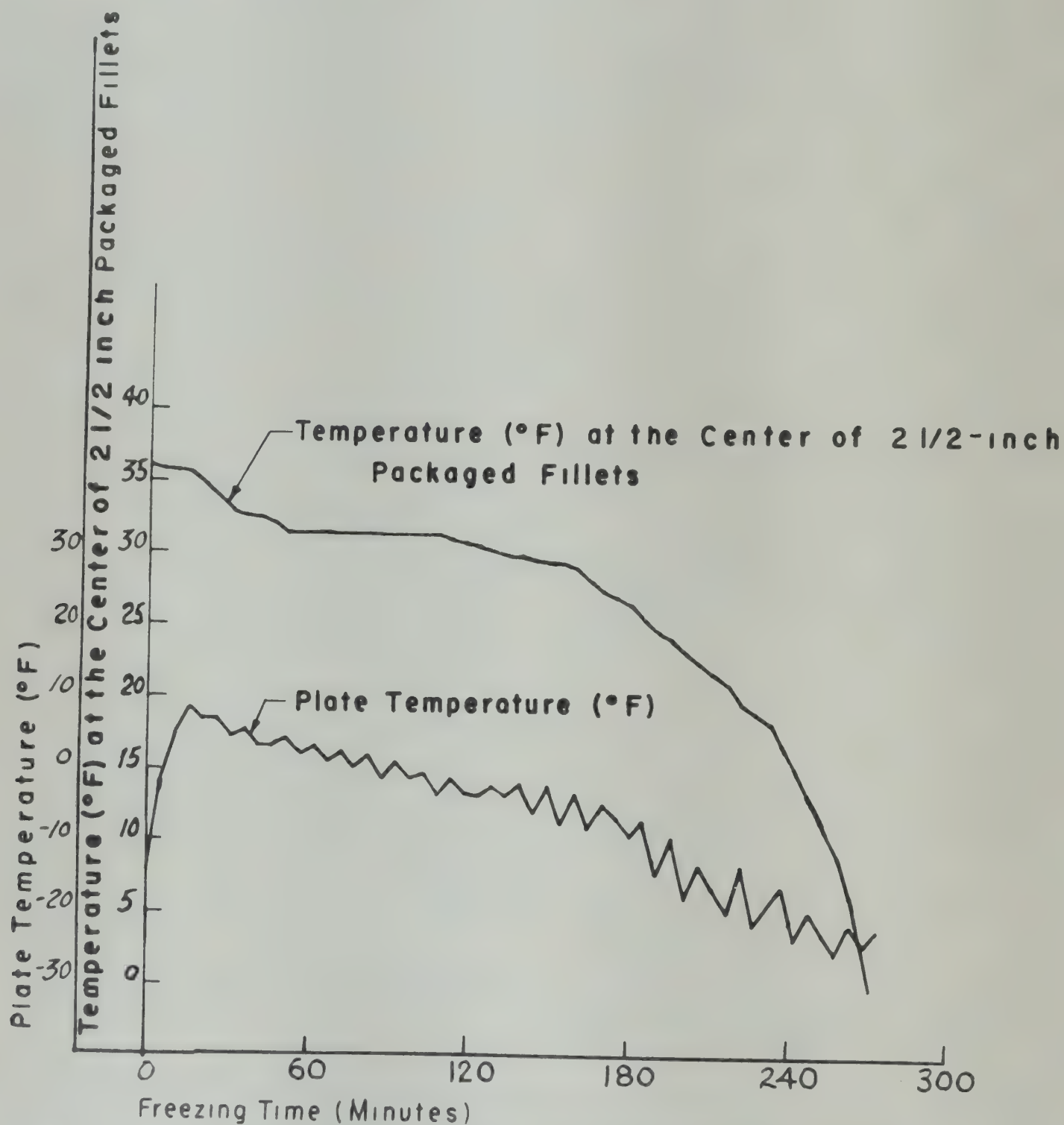


Figure 7.--Freezing $2\frac{1}{2}$ -inch-thick packaged fish fillets in a multi-plate compression freezer.

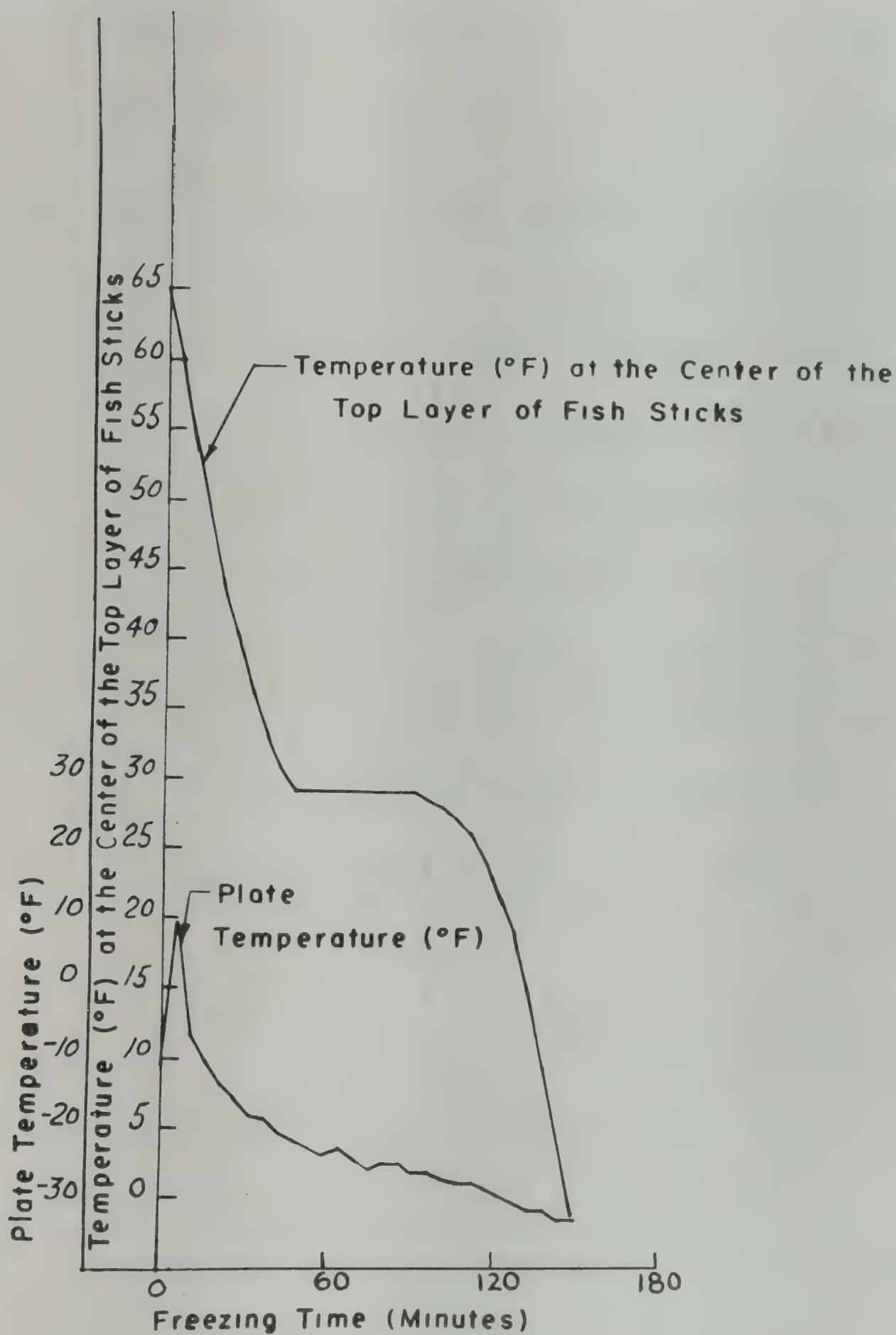


Figure 8.—Freezing $1\frac{1}{2}$ -inch-thick (10-ounce) packages of fish sticks in a multiplate compression freezer.

To obtain fast, efficient freezing, the following precautions should be taken:

1. Maintain the plates at a low temperature prior to loading the freezer.
2. Keep the freezer doors closed, except when loading or unloading, thereby preventing excessive frost from building up on the plates.
3. Use proper-sized spacers.
4. Package fish fillets properly, leaving as few voids as possible.

The advantages of the multiplate freezer are:

1. It produces a uniform well-shaped package with a minimum of voids.
2. It requires a minimum amount of floor space.
3. It freezes packaged fish fillets quickly and economically.
4. It does not require defrosting of the plates, if the freezer is operated properly.

The disadvantages of the multiplate freezer are:

1. It requires much handling in loading and unloading the products.
2. It freezes very slowly those products with a dead-air space in the package.
3. It requires large storage space for pans and spacers.

Continuous-Type Multiplate Freezer

The continuous-type multiplate freezer is similar to the batch-type multiplate freezer in that the same method of freezing is employed but is different in that the products are loaded and unloaded automatically. The freezer is available in 1 or in 8 stations, with respective capacities of 1,750 or 14,000 10-ounce packages of fish sticks. The larger-sized freezer consists of 8 stations and can be enclosed in a refrigerated room approximately 34 feet long, 20 feet wide, and 12 feet high (figure 9). This freezer will handle packages ranging in thickness from $\frac{7}{8}$ inch to $2\frac{1}{2}$ inches. The adjustment to new package size can be made by means of four exposed screws.

Packaged fish products are fed directly from the wrapping machine,

by a belt conveyor, through an opening in the walls of the refrigerated room onto eight roller-type loading stations at the front of the freezer.

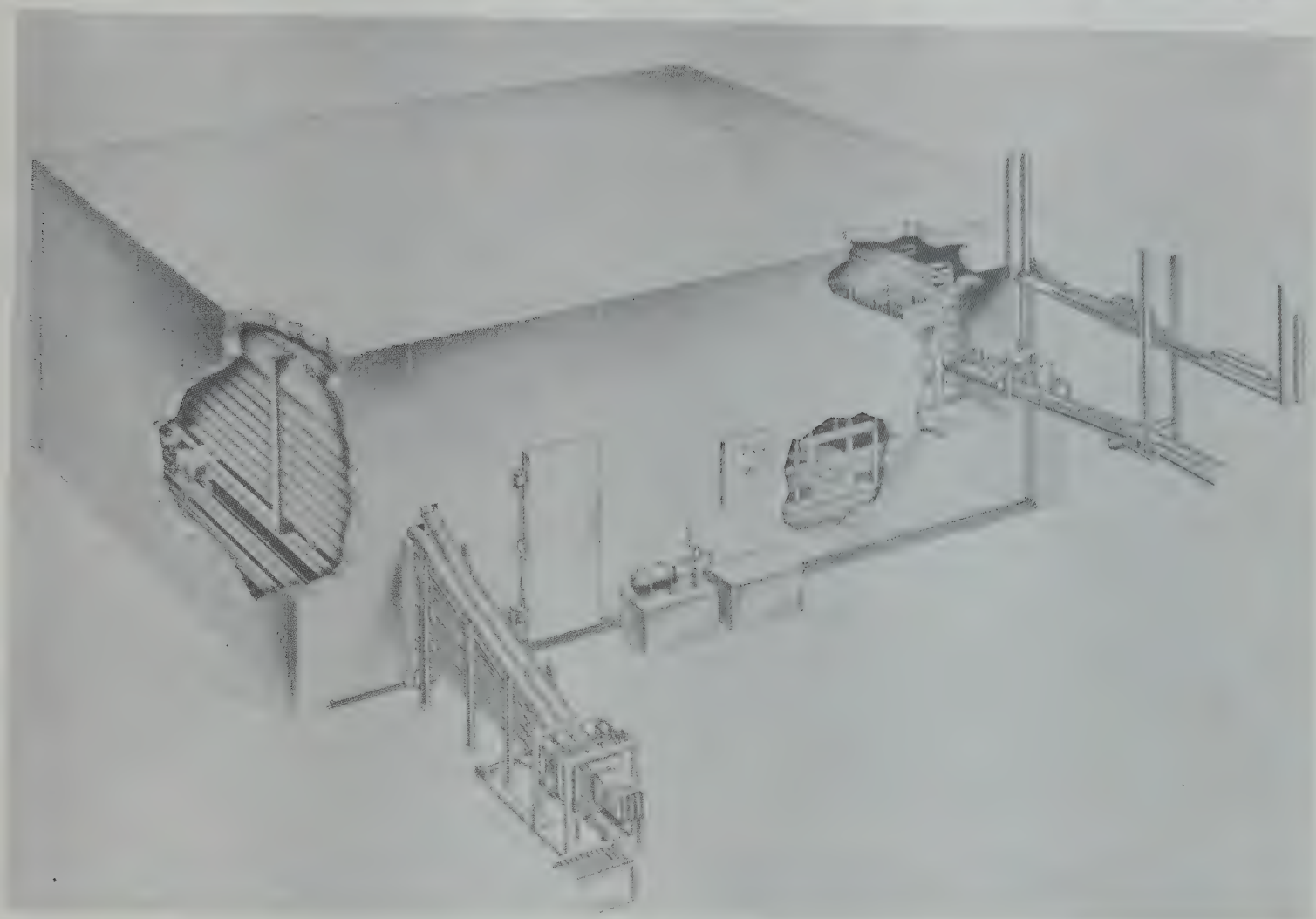


Figure 9.—A continuous multiplate compression freezer. (Photo courtesy of Patterson Freezer Corporation)

Electronic devices control the loading of each station so that, when one station is loaded, the conveyor moves up to the next station, until all eight loading stations are filled. When loading, each station receives one full row of packages at a time. The stations consist of upper and lower aluminum freezing plates. During each loading cycle, a movable frame causes the lower freezing plate of each station to move forward and down, thereby opening the station. The forward and back action of the lower plate forces the rows of packages to move toward the rear of the freezer. The loading cycle continues until all eight stations are completely filled. When the freezer is filled, each incoming row of packages forces out a frozen row of packages from the other end of the machine on each of the eight levels. The frozen packages are then conveyed to an automatic cartoning machine located outside the refrigerated room.

This freezer is ideally suited for the freezing of packaged, pre-cooked fishery products and fish fillets packaged in 1-pound commercial boxes. The main advantage of this freezer over the conventional multiplate freezer is a large-capacity frozen-product output with a minimum

amount of handling.

Blast Freezers

The blast freezer was one of the first devices used for the quick freezing of fishery products. In the early types, cold air was circulated at low velocity over the products while they were being frozen. These earlier systems were later modified so as to force cold air at high velocities and much lower temperatures over the products, to reduce the freezing time. The two main types of blast freezers in wide use today are blast rooms and tunnel freezers.

Blast Rooms

The size of the blast room depends primarily on the amount of fish the freezer is designed to handle. A typical blast room is approximately 60 feet long, 12 feet wide, and 8 feet high; and it has a capacity of 40,000 pounds of packaged fish fillets. The low temperature necessary for freezing (-40° F.) is produced by air circulating around $1\frac{1}{2}$ -inch-diameter steel pipe coils flooded with ammonia and located above the freezer ceiling. The required air circulation is maintained by five 5-hp. squirrel-cage fans located in front of the coils. These fans draw the air through the coils and force it down along the freezer wall, where baffles direct it across the products. Two-stage ammonia refrigeration equipment is used to supply the necessary refrigeration.

The packaged fish fillets are received on skids from the fish processors. The products are then removed from the skids and loaded on buggies. The buggies consist of a series of galvanized steel shelves 4 inches apart, supported by an angle-iron frame on each side. The base of the buggies is also of angle iron and has 4 small wheels to facilitate movement. Each buggy will hold 1,000 pounds of fish fillets packaged in 10-pound commercial boxes. The buggies, after being loaded, are pushed into the freezer. When the freezer is full (10 buggies deep and 4 across), the freezer door is closed, and the fans are turned on. The time required to freeze $2\frac{1}{2}$ -inch-thick 10-pound boxes of fish fillets is approximately 16 hours. The blast room freezes products much slower than does the tunnel-type freezer, because of the considerable decrease in air velocity due to the large number of buggies in the freezer. This freezer is ideally suited for freezing a large quantity of fish over a comparatively long period of time. The time required to load and unload the freezer is much less than that required for the sharp or plate freezer.

Tunnel-Type Freezer

A typical tunnel-type freezer (figure 10) consists of a room approximately 26 feet long, 5 feet high, and $3\frac{1}{2}$ feet wide, with a capacity of 9,900 pounds of packaged fish fillets. Finned pipe coils flooded with

ammonia provide the low temperature necessary for freezing. A 25-hp. squirrel-cage fan, located in front of the coils, draws air through the coils and forces it out through a duct placed at the front end of the freezer. The cold air, at temperatures of -40° to -50° F., is forced around the products located on the buggies, at a velocity of 500 to 1,000 feet per minute.

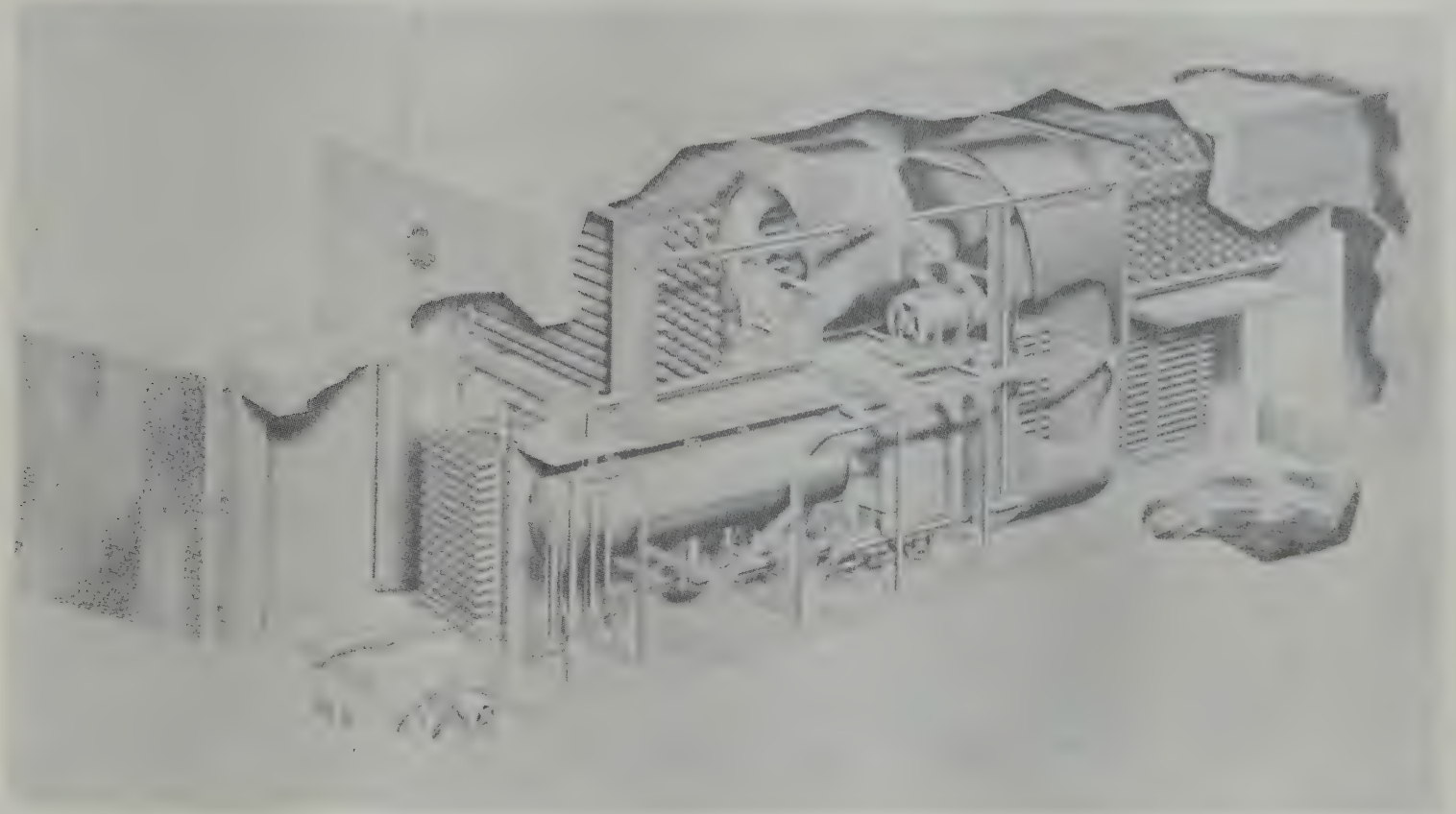


Figure 10.--A tunnel-type blast freezer. (Photo courtesy of York Corporation, York, Pa.)

An overlap freezer door is located at each end of the freezer, and a pair of vestibule-type doors are located approximately 6 feet in front of it. The space between the vestibule doors and the rear of the freezer is called the precooling chamber. An endless-chain conveyor, located at the rear of the freezer, engages a pawl on the buggies and carries them onto a pair of angle-iron tracks into the freezer. A button operates the conveyor and controls the rate of progress.

This type freezer is designed so that either a continuous process or a batch process can be employed. The packaged fish fillets are received from the processors and loaded on the shelves of buggies, which are approximately 3 feet wide, 3 feet long, and 5 feet high. Each buggy will hold approximately 1,000 pounds of 10-pound boxes of fish fillets. The buggies, when loaded, are pushed into the precooling chamber, where the continuous-chain conveyor carries them into the freezer. The freezer will hold 10 buggies: 9 in the freezer chamber, and 1 in the precooling chamber.

When the tunnel is used as a continuous freezer, the buggies are put into and removed from the freezer at predetermined time intervals, depending on production output and the freezing time of the product being handled. When the tunnel is used as a batch freezer, it is loaded to its full capacity of 9 buggies; after the freezing time has elapsed, these buggies are then removed to cold storage.

This type freezer is suitable for freezing packaged fish fillets, precooked fishery products, canned fishery products, and large fish in the round. When fishery products are frozen in 1-pound, or smaller, commercial packages, a special-type buggy shelf is employed, which consists of two reinforced pieces of aluminum mesh connected at two ends by an angle iron with a 1-inch air space between each piece. The shelves form a spacer between adjacent layers of packages, with the bottom part being in contact with the top of the lower layer of packages and the top part being in contact with the bottom of the upper layer of packages. Weight on the top layer of packages is distributed through the shelves to the lower packages, thereby preventing them from bulging due to expansion. The freezing time required for packaged fish fillets and precooked fish sticks are shown in figure 11.

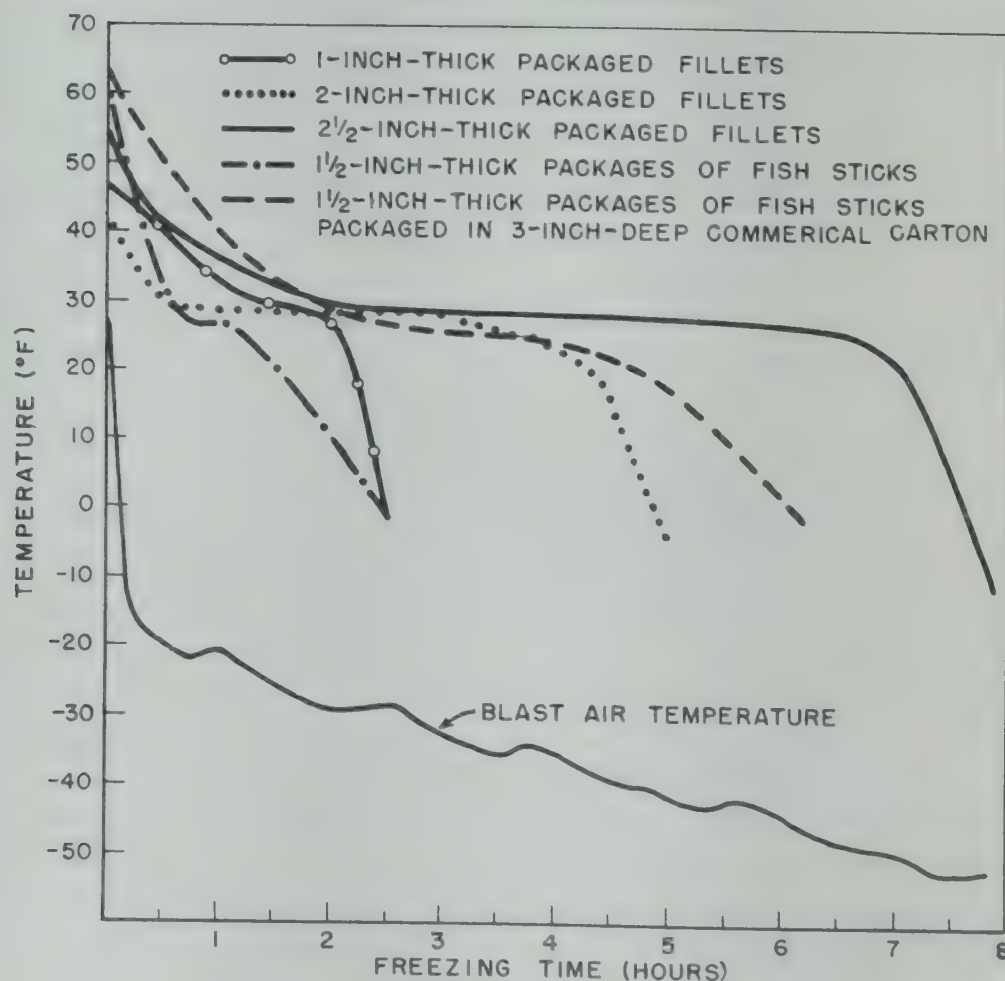


Figure 11.--Freezing packaged fish fillets and fish sticks in a tunnel-type blast freezer (air velocity 500-1000 feet per minute).

Advantages of the tunnel-type blast freezer:

1. It requires only a minimum amount of product handling.
2. It has a high frozen-product-capacity output per square foot of space.
3. It can freeze large bulky packages of fishery products satisfactorily.
4. It is suitable for freezing fishery products in packages and in cans, or in the round.

Disadvantages of the tunnel-type blast freezer:

1. It requires special buggy shelves to be used when freezing packaged fish fillets and fish sticks in the 1-pound and smaller-size packages.
2. It requires more electrical energy than do the plate or sharp freezers, because of the energy needed to operate the fan.
3. It requires that the packaged products be all of the same thickness, to allow for the proper flow of air.
4. In a batch process, the products at the front end of the tunnel freeze the fastest, and the variation of air flow in different buggies affects the freezing rate.
5. It must be defrosted periodically, resulting in lost production.
6. It requires more time for freezing packaged fish fillets than does the plate freezer.
7. It has higher maintenance costs than have plate or sharp freezers.
8. It cannot freeze small loads economically.

Immersion Freezers

The immersion-type freezer is used largely for the freezing aboard a fishing vessel of fish—such as haddock, cod, and tuna—or shellfish—such as shrimp. The product is frozen by immersing it in an agitated cold brine solution of a fixed concentration and temperature.

The type of immersion freezer employed depends on the nature of the product being frozen. Although sharp, blast, or plate freezers are

somewhat versatile inasmuch as they will freeze a variety of different fish species in various forms, the application of the immersion freezer is restricted largely to the specific type of fish for which it was designed.

The following factors should be considered in the selection of a commercial immersion freezer aboard a fishing vessel: (1) type of fish to be frozen, (2) freezing time for average weight fish, (3) handling requirements, (4) source of available power, (5) refrigeration-equipment space requirements, (6) average catch, (7) space required to hold a portion of the fish prior to freezing, (8) cost and dependability of refrigeration equipment, (9) effect of brine on the product, (10) freezing temperature of the brine, and (11) cost of maintaining a clean brine supply. The following describes various types of immersion freezers employed on vessels.

An Immersion Freezer Designed to Freeze New England Groundfish Aboard a Fishing Vessel

An immersion-freezing system designed to freeze New England groundfish has proven successful in use on the experimental trawler Delaware, which is operated by the Fish and Wildlife Service laboratory, East Boston, Massachusetts. This system will freeze approximately 850 pounds of fish per hour. The system is of the indirect type, with sodium chloride brine (23 percent salt by weight) being used as the cooling medium. The freezing is accomplished within a rectangular-shaped brine tank (figure 12) located in fish hold number 2. This tank is 8 feet long,

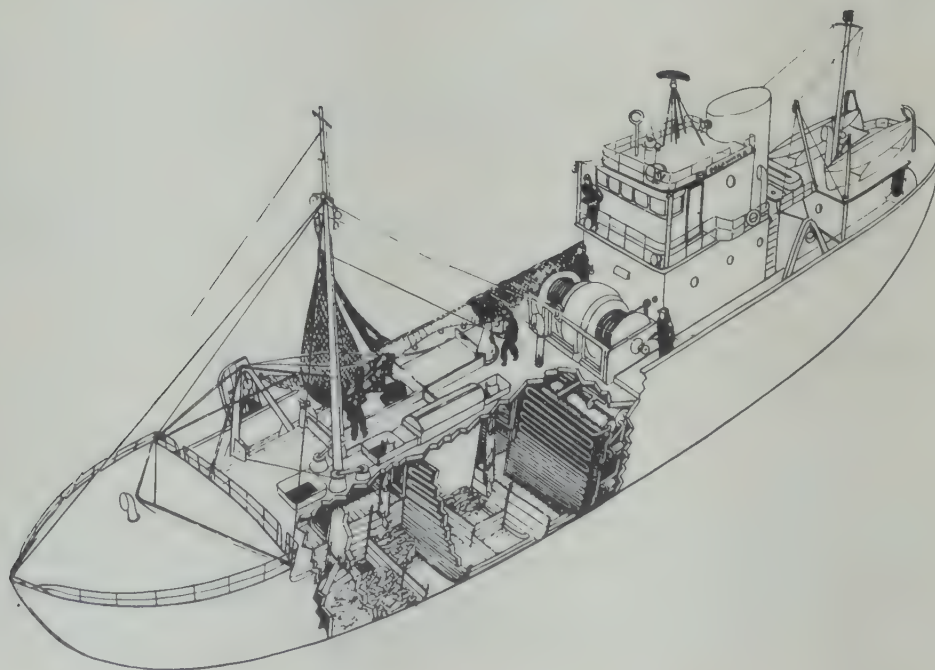


Figure 12.--Cutaway view of the Delaware showing brine freezing tanks and fish storage bins.

14 feet deep, and 5 feet wide, with a capacity of 35,000 pounds of brine. The tank extends from the floor of the fish hold to about 30 inches above the deck. The tank cover has two doors, one on each side, so that the fish can be loaded and unloaded simultaneously. There are 11, cylindrical, galvanized, metal-mesh baskets connected at each end by a continuous chain drive, located within the freezer tank. An electric motor placed in a watertight enclosure on deck adjacent to the tank is used to provide the power for the clockwise and counterclockwise rotation of the baskets through the brine.

The brine in the freezer tank is circulated by a centrifugal-type pump through a flooded-type brine cooler, where it is cooled to the proper temperature. A 25-ton absorption refrigeration machine located in a watertight compartment forward of the engine room is used to provide the necessary refrigeration. An ethanol solution, at a temperature of -10° F., circulating through steel coils located on the walls and ceilings of each of two holds, maintains these holds at 0° F. An additional small fish hold is used for icing fish for experimental purposes.

The freezing operation is as follows: Fish, after being caught, are put, in the round, into the cylindrical baskets located in the brine tank. Each basket will hold 500 pounds of fish. After the baskets are loaded from the deck, the freezer-tank doors are closed, and the basket-drive motor is started, causing the baskets to rotate through the brine. The movement of the baskets through the brine provides adequate brine circulation around each fish, thereby insuring uniform, quick, and efficient freezing. Each basket is numbered. Fish of approximately the same weight are put together in the same basket. After the proper freezing time elapses (table 1), the fish are removed from their respective baskets, glazed and conveyed by aluminum chutes to the cold-storage hold. The fish are then stored in cold storage until arrival of the vessel at the laboratory, at which time the frozen fish are discharged, thawed, filleted, and refrozen.

The advantages of this type of freezer are:

1. It freezes products quickly and efficiently.
2. It is versatile, inasmuch as it can also freeze tuna or shrimp, quickly and efficiently.
3. It requires a minimum amount of handling.
4. It uses a sodium chloride brine, which is relatively inexpensive.
5. It produces a high-quality frozen fish.
6. It has low maintenance costs.

Table 1.--Freezing time for whole round cod and haddock, of various thicknesses, in sodium-chloride brine at 10° and 0° F.

Thickness ^{1/} of fish	Approximate ^{2/} round weight of fish	Freezing time at:	
		10° F.	0° F.
<u>Inches</u>	<u>Pounds</u>	<u>Minutes</u>	<u>Minutes</u>
1½	1 - 1½	55	35
2	1½ - 2½	85	55
2½	3 - 5	125	80
3	4½ - 7½	170	110
3½	7 - 10	220	145
4	9 - 12	280	185

^{1/} Side to side thickness (smallest diameter of a cross section) at the point of maximum girth.

^{2/} Round weight is generally 10 to 15 percent higher than is dressed weight.

The disadvantages of this freezer are:

1. Careful temperature regulation is required in the brine cooler to eliminate the possibility of the brine freezing out at -6° F., which might result in bursting tubes within the brine cooler.

2. The penetration of salt into the fish will be excessive if they are left in the brine considerably longer than the required freezing time.

An Immersion Freezer Designed for the Freezing of Shrimp Aboard a Fishing Vessel

The limited storage life of iced shrimp has recently led to the design and installation of commercial immersion freezing plants aboard several shrimp fishing vessels. A sodium chloride brine solution--its use having been proven in other types of immersion freezers--was used first (Dassow 1954).

The shrimp frozen in this solution were of good quality; however, they sometimes fused together into a solid mass upon freezing, and subsequently dehydrated in cold storage unless protected by spray glazing.

Mingledorff (1954) found that, by using a brine solution composed of salt and sugar, the shrimp would not fuse together upon freezing and that they could be stored for a period of 60 days or more without dehydration. This solution is presently being employed in the immersion freezers aboard several shrimp fishing vessels.

The freezing is done in a stainless-steel tank approximately 5 feet wide, 7 feet long, and 4 feet high, which is located on the deck of the vessel (figure 13). The brine temperature is maintained at 0° F. by Freon 12 circulating through plates placed within the tank. A hydraulically driven propeller inside the tank provides the necessary brine agitation.



Figure 13.--Fresh shrimp entering the freezing tank aboard the shrimp trawler Prince Charming. (Photo courtesy of Mingledorffs, Inc.)

The refrigeration is supplied by a diesel-driven Freon 12 compressor. The frozen shrimp are maintained at 0° F. by an additional diesel-driven compressor supplying refrigeration to overhead plates located within the holds.

The freezing operation is as follows: Shrimp, after being caught, are headed and washed. They are weighed in 50-pound lots and put into stainless-steel wire baskets. These baskets, in turn, are set in the freezing tank (figure 13). When 15 minutes elapses, the baskets are picked up, and the shrimp are dumped into containers, which are then placed in a cold-storage room. At the end of each day, the shrimp are put into 50-pound master cartons. By this method, it is possible to process and freeze more than 3,000 pounds of shrimp in 10 hours.

The advantages of this type of freezer are that it (1) produces a high-quality product, (2) reduces handling costs, (3) eliminates shore processing costs, (4) freezes products quickly and efficiently, (5) permits thawing of individual shrimp rather than 5-pound blocks of fused shrimp, and (6) provides a protective glaze, which reduces dehydration in cold storage.

An Immersion Freezer Designed to Freeze Tuna Aboard a Fishing Vessel

To obtain a constant flow of high-quality tuna from fishing vessel to cannery, the tuna must be frozen on board the vessel. The freezing method employed is quite complicated because of the large size of the fish often being handled. The following describes the equipment and methods employed on the tuna bait boat or clipper.

A typical modern tuna clipper has 10 to 14 freezing wells located below decks on the after part of the vessel. Each well has a capacity of approximately 20 tons of frozen tuna. The inside walls are lined with 1½-inch-diameter galvanized pipe coils. Ammonia expanding through these coils provides the necessary refrigeration effect. The refrigerant is supplied by three compressors each driven by 25-hp. motors.

The freezing operation is as follows: The tuna, shortly after being caught, are put into freezing wells filled with refrigerated sea water (preferably at 30° to 32° F.). When the wells have been loaded to capacity with fish and the temperature lowered to 30° to 32° F., salt is gradually added to the water and mixed by means of a brine-circulating pump to form a dense brine solution, using about ¾ sack of salt for each ton of fish in the well. Ammonia expanding through the coils located in the wells cools the brine to 20° F. or lower. The fish are held in the well until their internal temperature is lowered to at least 23° F. (preferably 10° to 15° F.), at which time the brine is pumped overboard. The well is then used as a still-air cold-storage room, with the refrigeration effect being furnished by the same coils that were used to chill the brine. This well is known as a dry well. The temperature of the ammonia within the coils is maintained at -10° to 0° F.,

thereby eventually producing a dry-well temperature of 10° to 20° F.

Before the arrival of the vessel at the cannery, the fish are started to thaw in order that they will be ready for unloading as soon as the ship docks. The procedure used is as follows:

(1) The refrigeration in the dry well is shut off.

(2) Approximately 8 hours later, the dry well is flooded with sea water.

(3) The brine circulator is started up.

(4) The same amount of salt is added as was added to lower the well temperature originally.

(5) The brine is circulated until a brine temperature of 28° F. is reached. (This step may take approximately 48 hours, depending on the brine circulation and hold capacity.)

(6) Small amounts of sea water are added to the wells until the brine reaches 33° F.

(7) The 33° F. brine is circulated until the fish reach an internal temperature of 25° F.

(8) The fish are unloaded into the cannery.

The advantages of this type of freezer are:

1. It requires a minimum amount of product handling.

2. It has low maintenance costs.

3. At rated capacity, it produces a good-quality frozen fish, in large volume.

4. It requires a minimum amount of space because fish are frozen, stored, and thawed in the same tank.

The disadvantages of this type of freezer are:

1. It freezes products very slowly.

2. It requires careful control of temperature because, if proper temperatures are not maintained within very close limits, spoilage of the product may result. This control requires careful loading so as not to overload the well and thus exceed its freezing capacity.

3. It is not versatile, inasmuch as this freezer is not suitable

for freezing groundfish, mackerel, or shellfish.

4. It requires large amounts of salt for both freezing and thawing.

5. It requires a high-capacity refrigeration system and considerable auxiliary power for large-volume brine pumps.

6. With small tuna, like skipjack, a slow rate of freezing in brine often leads to excessive absorption of salt by the flesh.

BIBLIOGRAPHY

AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

1954-55. Air Conditioning Refrigerating Data Book, Applications Volume, Fifth edition. American Society of Refrigerating Engineers, New York.

AMERICAN SOCIETY OF REFRIGERATING ENGINEERS

1955-56. Air Conditioning Refrigerating Data Book, Design Volume, Ninth edition. American Society of Refrigerating Engineers, New York.

BIRDSEYE, CLARENCE

1929. Some aspects of packaging and quick freezing perishable flesh products, Parts 1, 2, and 3. Industrial and Engineering Chemistry, vol. 21, Part 1 - No. 5, pp. 414-417; Part 2 - No. 6, pp. 573-576; Part 3 - No. 9, pp. 854-857.

CARLSON, C. B.

1948. Refrigerated tuna carrier operations in the tropics. Pacific Fisherman, vol. 46, No. 4, March, pp. 35-37.

DASSOW, JOHN A.

1954. Freezing Gulf-of-Mexico shrimp at sea. Commercial Fisheries Review, vol. 16, No. 7, July, pp. 1-9.

FARBER, L.

1955. How refrigeration at sea best protects tuna quality. Pacific Fisherman, vol. 53, No. 8, July, p. 30.

MINGLEDORFF, W. L., Jr.

1954. Immersion freezing. Southern Fisherman, vol. 14, No. 12, December, p. 38.

SLAVIN, J. W.

1955. Technical Note No. 32 - Freezing rates and energy requirements for freezing packaged fish fillets and fish sticks in a multiplate-compression freezer. Commercial Fisheries Review, vol. 17, No. 7, July, pp. 21-26.

STEVENS, Garnet W.

1954. Brine freezing tuna at sea. Pacific Fisherman, vol. 52, No. 12, November, p. 44.

TAYLOR, H. F.

1927. Refrigeration of fish. U. S. Bureau of Fisheries, Document No. 1016.

TRESSLER, DONALD K., and EVERS, CLIFFORD F.

1947. The Freezing Preservation of Foods, Second edition. Avi Publishing Company, Inc., New York.

TRESSLER, DONALD K., and LEMON, J. M.

1951. Marine Products of Commerce, Second edition. Reinhold Publishing Company, New York.

FREEZING FISH AT SEA—NEW ENGLAND

Part 1 - Preliminary experiments, by Jean C. Hartshorne and Joseph F. Puncochar, Commercial Fisheries Review, vol. 14, No. 2, February 1952, pp. 1-7 (Sep. No. 306).

Part 2 - Experimental procedures and equipment, by H. W. Magnusson, S. R. Pottinger, and J. C. Hartshorne, Commercial Fisheries Review, vol. 14, No. 2, February 1952, pp. 8-15 (Sep. No. 306).

Part 3 - The experimental trawler "Delaware" and shore facilities, by C. Butler, J. F. Puncochar, and B. O. Knake, Commercial Fisheries Review, vol. 14, No. 2, February 1952, pp. 16-25, (Sep. No. 306).

Part 5 - Freezing and thawing studies and suggestions for commercial equipment, by H. W. Magnusson and J. C. Hartshorne, Commercial Fisheries Review, vol. 14, No. 12a, December 1952-Supplement, pp. 8-23 (Sep. No. 328).

Reprinted July 1963
November 1966

C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION
H. S. B. B. B. MANGALORE-1.

Created in 1849, the Department of the Interior--a department of conservation--is concerned with the management, conservation, and development of the Nation's water, fish, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States--now and in the future.



UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES
WASHINGTON, D.C. 20240

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF THE INTERIOR

OFFICIAL BUSINESS

Return this sheet to above address, if you do
NOT wish to receive this material ☐, or if
change of address is needed ☐ (indicate
change).

C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION
Golden Harbor, MANZALONE-I.

00
C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION,
MELBA BAZAAR, MANGALORE-1.

HANDLING FRESH FISH

REFRIGERATION OF FISH - PART 2



UNITED STATES DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE

BUREAU OF COMMERCIAL FISHERIES

Fishery Leaflet 428

C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION,
MADRAS BAZAAR, MANGALORE-1.

Lib. NO. 68/2-8-67.
2

UNITED STATES DEPARTMENT OF THE INTERIOR, Stewart L. Udall, *Secretary*
FISH AND WILDLIFE SERVICE, Clarence F. Pautzke, *Commissioner*
BUREAU OF COMMERCIAL FISHERIES, Donald L. McKernan, *Director*

Fishery Leaflet 428

REFRIGERATION OF FISH - PART TWO

HANDLING FRESH FISH

By Charles Butler (Section 1); John A. Dassow (Section 2); and
C. J. Carlson, Joseph Carver, and Martin Heerdt (Section 3)

Table of Contents

	Pages
Section 1 - Spoilage of Fish Prior to Freezing	1 - 12
Section 2 - Handling of Fish Aboard the Vessel	13 - 38
Section 3 - Handling Fresh Fish at the Shore Plant	39 - 84

(A detailed table of contents is at the beginning of each section)

* * * * *

This leaflet is part two in a series of five on "Refrigeration of Fish." Titles of the other four leaflets are:

- Part 1 (Fishery Leaflet 427) -- Cold-Storage Design and Refrigeration Equipment
- Part 3 (Fishery Leaflet 429) -- Factors to be Considered in the Freezing and Cold Storage of Fishery Products
- Part 4 (Fishery Leaflet 430) -- Preparation, Freezing, and Cold Storage of Fish, Shellfish, and Precooked Fishery Products
- Part 5 (Fishery Leaflet 431) -- Distribution and Marketing of Frozen Fishery Products

The five leaflets in this series are prepared under the general supervision of Charles Butler, Chief, Technological Section, Branch of Commercial Fisheries, Washington, D. C., and edited by Joseph W. Slavin, Refrigeration Engineer, Fishery Technological Laboratory, East Boston, Massachusetts, and F. Bruce Sanford, Chemist, Fishery Technological Laboratory, Seattle, Washington.

C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION,
HARMA BAZAR, MANGALORE-1.

SECTION 1

SPOILAGE OF FISH PRIOR TO FREEZING

By Charles Butler, Chief,
Technological Section, Branch of Commercial Fisheries*

TABLE OF CONTENTS

	Page
Introduction	2
Causes of deterioration	3
Enzymatic action	4
Oxidative action	5
Bacterial action	6
Bacteria in the water	6
Bacterial problems aboard the fishing vessel	7
Bacterial problems at the shore processing plant	9
The processing of fish fillets and steaks	10
The processing of shellfish	10
The packaging of fishery products	11
Literature cited	11

* Fish and Wildlife Service, Department of the Interior, Washington 25,
D. C.

INTRODUCTION

To the qualified wine taster, there is a wide range of aroma, bouquet, color, and flavor within the upper and lower limit of acceptability. Small wonder, then, that with a food commodity as diverse in character as fishery products, there is present a similar range in flavor, aroma, texture, and color. This fact is forcefully brought out when restaurant managers and home economists attempt to introduce a new product or a new method of preparation for an established product. Fishery products that retain these initial desirable qualities provide the consumer with each of the essential ingredients for an appetizing and completely nutritious meal.

The delicate and ephemeral aroma and flavor characterizing each individual member of the large family of fishery products as a treat unto itself is a zealously preserved quality in many countries, such as Denmark where fish often are purchased alive. The lavish care taken to supplement and enhance these characteristics with expert cookery accounts in large part for the "rave" notices Americans give fish eaten there. Without the supreme initial quality of the fish, the dish is something less than the Danes are accustomed to expect. By contrast, we in this country have all too often been painfully aware of the strong odor permeating the apartment house or private home where "fresh" fish is being fried for the evening meal.

Extensive tests by the Educational and Market Development Section of the Fish and Wildlife Service have shown that children at school lunch rooms will overcome a disinterest in fish dishes, possibly developed at home through lack of proper preparation of quality raw materials, or even an unreasoned bias developed through disparagement of fish by parents and companions, when the servings are from high quality materials, tastefully prepared, and appealing to the eye.

Adults, likewise, have developed a liking for fish dishes through demonstrations by Fish and Wildlife Service home economists. For example, at a class of Army cooks and bakers, three lots from the same purchase of ocean perch fillets were prepared by three different recipes and served to a taste panel. Questions were asked regarding the particular species of fish used for each of the three "different" dishes. The participants expressed approval of the servings, although they had been emphatic in their dislike for fish before the taste test.

Family groups participating in taste tests at another laboratory expressed surprise at the excellence of the entree served from frozen fillets. The chief question was: "Where can I get fish like that to cook for my family?"

On another occasion, a group of fishery industry executives were served a luncheon where frozen fillets were prepared as the entree.

First quality fish, prepared with the proper cooking time, seasoned to bring out--not to mask--the true flavor, and served attractively were so well accepted that the cook had several offers for a job to open a restaurant by men who, although in the fish business, seldom found their product available in such an appetizing form.

It is thus evident that there is a real need for the encouragement of highest quality fish production. Persons who now eat fishery products from habit, or for economy reasons, would without question eat them more frequently if better raw materials were made available. That large segment of people who seldom eat seafoods at home could be interested if they were induced to try pan-ready, high-quality products, with a suggested recipe, thereby making the ordinary homemaker into a skilled chef. The even larger group of persons who do not eat fish because they do not like it can never be won over by offerings of inferior servings no matter at what low price. They can be interested when there is offered something of sufficient merit to stimulate their appetites. Then comes the opportunity to open up the wide demand for tasty variety that fishery products are uniquely able to supply.

This section is devoted to a discussion (1) of the various forms and pathways of quality deterioration and (2) of methods of minimizing such losses prior to freezing, in order to obtain a product with the characteristically pleasing flavor and aroma of freshly caught fish.

CAUSES OF DETERIORATION

The dictionary defines "spoil" as "to cause to decay and perish or to become of less or no use, value or the like." There are, in other words, several degrees or stages in the process of spoilage. Obviously, no one would be expected to relish fish that had reached the "decay or perish" state. For a marketable product, then, we would expect to deal rather with the "to become of less use, value or the like" category as the lower limit of acceptability. In practice, this is actually too often the case, as there may be wide differences in the quality of fish offered for sale. They may all be edible in the sense that discomfort or illness will not result from ingestion. Food and Drug inspection may show no criterion for declaring them unfit for consumption. Yet--somewhere, somehow--the top quality has been lost.

To be in a position intelligently to preserve and protect fishery products from this loss, we must have a knowledge of the factors contributing to it. In this section, factors applicable from the point of capture to, but not including, preservation by freezing will be considered.

Quality loss in fish and shellfish is attributable to one or all of three principal causes: (1) enzymatic or autolytic action, (2) oxidative action, and (3) bacterial action. The order of onset for these, and their relative importance in causing deterioration, may vary

with such allied considerations as species and maturity, and method used in the capture and in the dressing and icing of the fish. Bacterial action is generally recognized as the most important cause, but the interrelation of all three actions will be described as well.

ENZYMATIC ACTION

All living animals--of which fish, mollusks, and crustacea are a part--derive essential materials for growth and maintenance through the digestion and assimilation of plants or of other animals. The animal, to accomplish this task, must break down the food eaten into a number of constituents that can pass through the walls of the digestive tract. After mechanical breakdown, as by chewing, chemical breakdown by the digestive juices and fluids takes over the task. In these fluids are agents called enzymes, some of which attack fats, others carbohydrates, and still others the protein portions of the food. When the combined physical-chemical process is finished, the food can be absorbed into the body tissues to furnish construction and maintenance materials, energy, or fat reserves. Within the tissues, other enzymes are available to draw upon the stored body reserves for maintenance--or energy-supplying materials if food materials are not available to the animal.

When the animal dies, the balance between the processes of body maintenance is upset. The enzymes, instead of acting on the food normally taken in, continue actively to digest any of the particular types of materials--such as fats, carbohydrates, or proteins--which they are capable of breaking down. The result is the alteration of complex body tissue to less complex forms--a reversal of the normal process of digestion, assimilation, growth, and maintenance. Several names are used to describe this process of breaking down: autolysis, biochemical changes, enzymatic decomposition. The effect on the tissues begins at death; the rate and extent of alteration may be only controlled by some effective preservation method, such as use of heat, cold, or dehydration.

The chief observed effects of enzyme action are the softening of the fish flesh. In the case of some species, however, such as herring taken with food in the digestive tract, the autolytic action is so rapid that the belly walls may be pierced and the visceral mass converted to a semifluid state. Salmon under similar conditions may develop the discoloration called "belly-burn" where visceral organs have been in contact with the abdominal walls. Alford and Fieger (1952) reported that the spoilage in shrimp, known as "black spot," is enzymatic in nature. They reasoned that an enzyme reacts in the presence of air to oxidize the tissue substances and form melanin, with its characteristic black color.

These enzymatic reactions are intimately related to the mechanisms of deterioration that are utilized by bacteria. In fact, enzymes are secreted by the bacteria which act in the same general manner, and their attack is facilitated by the fish-enzyme actions. The unicellular

bacteria absorb and assimilate the breakdown products formed from the body of the host by the secreted enzymes. The bitter flavors and unpleasant odors, characteristic of spoiled foods, are derived from the breakdown products not absorbed by the bacteria. Fortunately, the same general rules apply for the minimizing of autolytic and of bacterial action in fish prior to freezing. They will be described in detail as part of the section on bacterial action.

OXIDATIVE ACTION

A second cause for deterioration in quality of fish prior to freezing results from oxidation and rancidity. Here again there is overlapping with enzymatic and bacterial activities. The fish contains fatty tissue that is protected during life by counterbalancing agents. At the death of the fish, the fat is attacked by the enzymes that are capable of doing so. Bacterial enzymes likewise react with the fat in the moist tissue. Usually, however, the bacterial action on the protein of the fish so rapidly produces undesirable odors and flavors that those developed as a result of the deterioration of the fat may be masked or of lesser importance, at the iced-fish stage. If, however, high quality fish is frozen, the slow but continuing oxidation and development of rancidity may then become a more serious problem. For example, even fish of very low oil content, such as cod or haddock, will develop the so-called "salt-fish" odor in frozen storage. At the other extreme, very fat fish, such as herring, may exhibit these changes after only a few days in ice. Once a fatty fish is frozen, the exposure of fat to the air during storage may result in surface oxidation of major significance in the development of the bitter flavor, the tallowy feel in the mouth, and the paint-like or "salt-fish" odor so characteristic of oxidized fish oil.

In summary, the oxidation and rancidity of fats can be caused by the single or combined action of tissue enzymes, bacterial enzymes, and exposure to air. The degree of susceptibility among fatty fish varies with species: mackerel, herring, and some of the salmon are quite vulnerable, whereas sablefish are quite resistant. Fish of relatively low fat content, such as cod or haddock, may develop rancidity, although at a much slower rate. Oxidation, besides causing rancidity, can cause other changes in fish. The fading of pigments that is observed in salmon or ocean perch and the development of off-color, such as in the yellowing of halibut and the browning of haddock, are results of oxidation.

Again, as in the case of enzymatic action, the same precautions--to be described under the following section on bacterial action--will serve to minimize the undesirable changes attributable to oxidative action in fish prior to freezing.

BACTERIAL ACTION

Bacteria are usually the most important causes for deterioration in fish, as in other protein foods. They are present in air, water, and soil in innumerable forms, shapes, and species, each with a characteristic method of attacking which, although we do not see the organism with the naked eye, can be noted by the odors, flavors, or colors imparted to material on which they are acting. The effects of bacteria on fish may be described at three principal stages in the taking and processing prior to freezing: (1) in the water, (2) aboard the vessel, and (3) at the shore plant.

Bacteria in the Water

Since bacteria are present in water, the natural environment of fish, we may expect to find bacteria on exposed surfaces. The normal fish, for example, may have a heavy population of bacteria on its skin, gills, and alimentary-canal surfaces. As long as the fish is in robust health, with no major breach in the skin tissues, which act as a barrier to attack, the bacteria can be kept from doing any serious damage. At death, however, the fish ceases to maintain the barriers to bacterial assault. Its tissues offer excellent material upon which the bacteria can feed. Enzymes secreted by the bacteria begin at once to liquify or digest the surrounding tissue so that the bacteria can absorb needed components of the tissue. The type of spoilage observed will be in large measure that attributable to the changes in the tissue caused by the attack of specific types of bacteria and from the byproducts generated by these bacteria when feeding on the tissues. The extent of spoilage is determined, in large part, by (1) the initial load of bacteria, (2) the temperature of the fish flesh, (3) the lapse of time, post-mortem, and (4) the type of sanitary procedures practiced.

Many of the fresh and frozen fish of commerce are taken in water at temperatures not very far above freezing: for example, cod at 35° to 44.6° F., haddock at 37.2° to 50° F., and halibut at 32° to 39° F. The bacteria adapted to these temperatures may be expected to continue their destructive activities on these fish after death, so long as the temperatures of storage are not low enough to provide an unfavorable environment. In the case of meat products, the normal bacterial population is adapted to growth at temperatures in the range of 101° to 107° F. The use of chill storage at 32° to 36° F. has a more pronounced retarding effect on these bacteria. The spoilage of fish is, therefore, a more difficult process to keep in check than is that of fresh meat products.

Although shrimp are taken in relatively warmer waters than are cod and haddock, Fieger, Lewis, and Green (1947) found few bacteria present as the catch was brought aboard the vessel and attributed spoilage largely to bacterial contamination and growth on board the vessel and ashore. Again, on shrimp, Williams (1949) found that cold-loving

bacteria were less abundant but that types normal to bottom muds were present.

The presence or absence of food in the alimentary tract of fish may also account for the presence or absence of bacterial populations, according to studies of some workers. Thus, it is probable that the bacterial load in the intestinal tract has been, at least in part, introduced from contact with and feeding on detritus or other animal life found in the bottom muds.

Studies of fish and other sea animals indicate that the number and type of bacteria found at time of capture varies with season, locality, species, water temperature, and method of capture. Analyses of sea water--taken at the surface, the mid-water, and the bottom levels in areas of fishery activities--show that the heaviest bacterial population is found in the bottom mud. We would expect that bottom-feeding species, such as those caught in the trawl fisheries, would have a large bacterial load. This inference is correct, but the effect of the gear enters into the problem, too. As the fish are often squeezed by weight of the mass in the trawl hoisted on deck, the contents of the intestines are expressed, adding to the contamination contributed by the skin and the gill-surface bacteria. This fact is corroborated by a comparison of bacterial counts of identical species of fish, such as cod, taken by trawling and by hand-lining. The latter, landed singly and with relatively careful handling, have a lesser bacterial load. Environmental differences may be shown from a comparison of the high bacterial loads of bottom feeders, such as cod, with the lower incidence for surface feeders, such as herring. Seasonal variations within the same species and the same gear category were found on haddock from the same grounds, the highest bacterial counts being in mid-summer for five successive years, according to Reay and Shewan (1949).

Bacterial Problems Aboard the Fishing Vessel

The effects of bacterial action may vary considerably, depending on the species of fish, the form in which they are landed, and the methods employed to protect quality. Some fish, such as mackerel or herring, caught close inshore may be stored on the vessel in the ungutted condition and without icing. Other fish taken in day fisheries by netting or trolling may be eviscerated, but not iced. Shellfish, such as oysters or clams, may be brought aboard and stored uniced in the shell.

For these round fish, careful washing in clean water, storage in clean boxes or shallow pans, minimization of damage from exposure to excessive pressure, and prompt protection from the sun and air temperatures will assist in keeping down bacterial action. Eviscerated fish can be carefully checked to insure removal of all visceral parts and blood, thoroughly washed in clean water, and promptly stowed out of the

sun and with the belly cavities down to promote free drainage of wash water. Shellfish must be very thoroughly washed free of mud and debris, promptly placed in clean storage space out of the sun, and preferably kept moistened with clean seawater.

Icing of fish is not a cure-all for quality preservation, but it does offer a considerable measure of protection from bacterial action. The importance of prompt and proper icing cannot be overstressed. Iced cod have been reported by Castell (1949) to spoil twice as rapidly at 37° F. (a common meat-chilling-room temperature) as at 32° F. Since a temperature drop of 5 degrees can reduce the rate of spoilage by 50 percent, it is very important to bring fish, after capture, rapidly to a suitable chill temperature of 32° to 34° F. Fish that can be kept for 14 days and still be edible at 32° F. can be kept for only 4½ days at 50° F. and for only 1½ days at 69° F.

Another reason for chilling fish rapidly is that the growth of bacteria goes through a lag phase or induction period, which increases in duration as the temperature of the flesh is lowered. In the case of Pseudomonas fluorescens, the lag phase is extended from 1 day at 52° F. to 4 days at 32° F. and to 6 days at 27° F.

The storage life of fish held at high temperatures for even a short time before icing is greatly reduced. Fish freshly caught and stored at 69° F. for 16 to 18 hours kept only half as long at 32° F. as did fish chilled to 32° F. immediately after they were caught.

Fish have different keeping qualities depending on species, season, and method of catching. Cod, haddock, flounder, and Norwegian winter herring keep for 12 to 15 days in good condition when chilled to 32° F. immediately after being caught. Pelagic fish with feed, dead shellfish, and those bruised and squeezed in catching spoil rapidly, even when iced.

Fieger, Green, Lewis, Holmes, and DuBois (1950) found that, with shrimp headed and properly washed on capture and then carefully iced, bacterial loads on the shrimp at the top of the pen section were of the order of 1 as compared with 100 for the shrimp on the bottom of the same pen, after 7 days' storage.

Campbell and Williams (1952) found that, with iced shrimp packed to facilitate rapid and direct removal of accumulated water from melting ice, the bacteria present actually reduced in number, after 8 days, but increased, after 12 days, at which time the quality also began to deteriorate.

In summary, icing aboard the vessel can be used to decrease bacterial action by use of bacteria-free ice for prompt, adequate, intimate, and continuing contact on all surfaces of the fish. This means, in essence, reduction of fish temperatures to as near 32° F. as possible, immediately after capture, and the maintenance of these conditions for as long as the

ice is needed to protect the fish.

Fish frozen at sea and stored under refrigeration have essentially the most protection possible from the deteriorative action of bacteria. The reasons for this effect can be shown by reference to the work of Bedford (1933). The range of temperature for development of marine bacteria is 18.5° to 80° F. Optimum growth occurs at 40° to 68° F. Bedford's extensive report on this subject presents data on 71 strains of bacteria isolated from sea water. Sixty-five grew at 32° F., 22 grew at 25° F., and 10 grew at 18.5° F. Most of the biochemical activities of marine bacteria continued steadily as the temperature dropped to 32° F. Many grew but could not produce enzymes at temperatures down to 21° F. It can therefore be seen that, below freezing, bacterial activity as a cause of spoilage is somewhat limited.

A differential count of bacterial strains by Haines (1934) showed that Staphylococci ceased growing below 50° F.; most strains of Escherichia coli, Bacillus proteus, and Micrococci did not grow at 32° F.; some strains of Bacillus proteus were capable of growing at 32° F.; many strains of Achromobacter, Pseudomonas, and various yeasts grew rapidly at 32° F., and down to 20° F. on unfrozen media. Thus although some strains of bacteria may continue to grow at the lowest possible temperature (32° F.) of iced fish, their activity drops off sharply as freezing takes place. In the freezing-at-sea studies carried on by the Fish and Wildlife Service laboratory at Boston, Massachusetts, brine at 5° to 10°F. was employed, with frozen storage at 5° F. for further protection of the fish en route to shore. Green (1949) reported a 62-percent reduction in bacterial counts on shrimp after 2 months' storage at 0° F. Although no direct bacterial counts were made on the fish frozen at sea in Boston, the organoleptic evaluations of these fish, at intervals over a 9-month storage period, did show that deterioration from bacterial action was either slight or nonexistent.

Bacterial Problems at the Shore Processing Plant

Fish protected aboard the vessel by careful handling, thorough icing, and good sanitation practices are next subjected to hazards of bacterial contamination during unloading, sorting, and processing ashore. The same factors need to be considered here: namely, time, temperature, care, and sanitation. There are, however, differences introduced in degree and kind at this stage in the handling of the product.

In the transfer from vessel to plant, the use of unclean baskets, boxes, tanks, conveyors, or other equipment, or the inserting of tines of the fork into the edible portion of the flesh offers opportunity for contamination. If the fish are allowed to remain longer than the absolute minimum time unrefrigerated prior to the next processing step--and at all intermediate stages--bacterial growth is rapid. All equipment coming in contact with the fish should be kept free of flesh particles and of slime. The use of a good detergent to remove soil, followed by a wash-down with water containing 25 p.p.m. of residual chlorine, is an acceptable procedure.

Fish unloaded from the vessel should be thoroughly iced, then held in a mechanically refrigerated cooler at about 30° to 32° F. in the shore plant until the trans-shipping or processing can be started.

Processing at the shore plant can result in serious bacterial contamination arising from contact of the fish with wood or metal surfaces, tools, gloves, or hands of workmen on which bacteria may be picked up through (1) expressing of liquids from the fish intestines, (2) growth of bacteria in slime and in flesh particles strewn about the work surface and not frequently washed away, (3) use of polluted water for washing, or (4) unacceptable personal sanitation habits of the workers. Castell (1948) found from studies in filleting plants that the major portion of bacteria causing spoilage at iced temperatures were brought into the plant on the fish themselves. Here again, the effective weapons against bacterial deterioration are low temperatures, cleanliness, and rapid handling. The following are some of the measures that should be taken to minimize bacteria in the processing of fish fillets and shellfish.

The processing of fish fillets and steaks.--Fillet-plant operations to protect the fish against bacterial action have been described by Hurley (1948). He found that the use of water containing 5 p.p.m. of residual chlorine at all stages from fish washer through the filleting line decreased the bacterial load of the fish by as much as 2,000 times over the previous methods. He also recommended use of water containing 25 p.p.m. residual chlorine for general plant clean-up at the end of each day.

Bacterial control in steak-preparation operations would differ principally in that the skin left on the fish should be even more carefully freed of slime and bacteria. Any protracted lag between the cutting of the steaks and the packaging and freezing stages could offer an excellent opportunity for continued spoilage.

The processing of shellfish.--Shellfish problems with bacterial spoilage are somewhat different from those for fish. Shrimp, taken usually many days from port, must be protected on the vessel. Ashore, continued sanitation, proper icing, fast handling, and processing by either cooking or freezing is essential to keep the quality of shrimp landed.

Scallops are usually shucked at sea and require essentially the same precautions as do shrimp.

Oysters, clams, and mussels are in a somewhat special category, since the U. S. Public Health Service, in cooperation with the states, has set up recommended practices for sanitation in the harvesting, shucking, and packaging of these shellfish. A manual describing the approved procedures may be obtained from the U. S. Public Health Service. Essentially, the problems are maintenance of low temperature and sanitation, but with products that grow in inshore areas, the possibility of pathogenic bacterial contamination is added to that of spoilage.

Crabs, too, pose serious bacterial problems. The crabs, when steamed, may be sterile, but good sanitation is essential to minimize bacterial contamination during the cooling and hand-picking stages. The use of chlorinated water for plant sanitation, frequent inspection of workers for health and for compliance with good personal sanitation, and rapid packing and chilling or freezing of the picked crabmeat can materially assist in producing an acceptable product.

The packaging of fishery products.--For fish or shellfish that are to be frozen, the packaging materials must be clean and free of bacteria. They should be sufficiently watertight to preclude recontamination of the product once it is packaged. The product to be packed should be at 50° F. or lower when packed, and the packages should be promptly frozen thereafter, to at least 0° F. at the center of the product.

When packaging fish for the fresh-fish trade, proper care must be exercised so that all the good work that went before will not be lost through spoilage at this stage. The fish must be chilled to 32° F. before it is packaged. MacCallum (1949) showed that the temperature of fish boxed at 50° F. and stored in ice had dropped to 44° F. only after 18 hours. The primary reason for the icing of fresh-fish shipments is to maintain the desirable low temperature. The container should, at the same time, protect the fresh fish from recontamination due to seepage of ice water or to other possible sources during transport.

LITERATURE CITED

ALFORD, JOHN A., and FIEGER, E. A.

1952. The non-microbial nature of the black spots on ice-packed shrimp. Food Technology, No. 6, June, pp. 217-219.

BEDFORD, R. H.

1933. Marine bacteria of the northern Pacific Ocean; the temperature range of growth. Contrib. Can. Biol. and Fish, N. S. No. 7, pp. 433-438.

CAMPBELL, L. L., JR., and WILLIAMS, O. B.

1952. The bacteriology of Gulf Coast shrimp. IV. Bacteriological, chemical, and organoleptic changes with ice storage. Food Technology 6, No. 4, April, pp. 125-126.

CASTELL, C. H.

1948. The control of fillet contamination in fish plants. Part II - The relationship between the initial contamination and the subsequent rate of spoilage. Fisheries Research Board of Canada, Progress Reports of the Atlantic Coast Stations No. 41, January, pp. 10-14.

CASTELL, C. H.

1949. Refrigeration temperatures and the keeping time of fresh fish. Fisheries Research Board of Canada, Atlantic Coast Stations, Progress Report No. 44, January, pp. 8-12.

FIEGER, E. A.; LEWIS, H.; and GREEN, M.

1947. For better shrimp cocktails. Southern Fisherman, 7, No. 3, January, pp. 204-205.

FIEGER, E. A.; GREEN, M.; LEWIS, H.; HOLMES, D.; and DuBOIS, C.

1950. Shrimp handling and preservation. Refrigerating Engineering, vol. 58, March, p. 244.

GREEN, M.

1949. Bacteriology of shrimp. Food Research, 14, No. 5, p. 392.

HAINES, R. B.

1934. The minimum temperatures of growth of some bacteria. Journal of Hygiene, vol. 34, p. 277.

HURLEY, STANLEY P.,

1948. In-plant chlorination gives excellent bacterial reduction at Gorton-Pew Fisheries Company, Ltd. Paper presented at the Fishery Technologists' informal meeting, Boston, Massachusetts.

MacCALLUM, W. A.

1949. Changes in cooling and transportation technique suggested for the marketing of fresh "fresh" fish. Fisheries Research Board of Canada, Progress Reports of the Atlantic Coast Stations, No. 45, April, pp. 11-14.

REAY, G. A., and SHEWAN, J. M.

1949. The spoilage of fish and its preservation by chilling. Advances in Food Research, vol. 2, p. 349, New York, N. Y. Academic Press, Inc.

WILLIAMS, O. B.

1949. Microbiological examination of shrimp. Journal of Milk Food Technology, vol. 12, pp. 109-110.

SECTION 2

HANDLING OF FISH ABOARD THE VESSEL

By John A. Dassow, Assistant Chief,
Pacific Coast and Alaska Technological Research*

TABLE OF CONTENTS

	Page
Handling procedure	15
Effect of fishing methods on quality	15
Relation of fish species to handling methods	17
Groundfishes	17
Halibut	19
Sablefish	19
Salmon	20
Tuna	22
Good "housekeeping" aboard the vessel	22
Sorting, dressing, and washing fish on deck	24
Fresh-water ice	27
Keeping time	27
How ice aids in preservation	27
Insulation	27
Ice contamination	27
Subcooling	28
Particle size	28
Ratio of ice to fish	28
Correct icing	29
Salt-water ice	30
Bactericidal ice	31
Mechanical refrigeration as an ice auxiliary	31
Other methods of holding fresh fish aboard the vessel	32
Refrigerated sea water	32
Live wells	34
Literature cited	35

ILLUSTRATIONS

Figure 1.—Dumping a load of groundfish aboard a North Atlantic trawler	17
Figure 2.—Putting trawl bag back over the side after discharge of a load of groundfish	17
Figure 3.—A load of groundfish aboard a North Atlantic trawler. The fish are ready for sorting, dressing, and icing	18

* Fishery Technological Laboratory, Seattle 2, Washington

	Page
Figure 4.--Unloading groundfish from a North Atlantic trawler	18
Figure 5.--Removing salmon from a drift gill at the mouth of the Stikine River in southeastern Alaska . . .	20
Figure 6.--Unloading salmon taken by purse seine gear near the San Juan Islands in Washington	21
Figure 7.--The fish bins in the hold of a North Atlantic trawler after the fish have been taken ashore . .	23
Figure 8.--Bringing a king salmon aboard a troller in southeastern Alaska. Note the "checkers" or sorting bins immediately in front of the fisherman	24
Figure 9.--Dumping a catch of mixed bottom fish aboard a trawler off the Oregon coast. The catch is mostly rockfish	25
Figure 10.--Unloading a catch of bottom fish from a trawler at a Seattle dock	30
Figure 11.--Barge with refrigerated sea-water tanks for holding salmon (Photo courtesy of Pacific Fish- erman)	33
Figure 12.--Unloading live dungeness crabs from the well of a crab boat at Ketchikan, Alaska	34

HANDLING PROCEDURE

The quality of landed fish depends primarily on the care and promptness with which they are handled and stored aboard the fishing vessel. If they are to be held fresh aboard the vessel for more than a few hours, the fish, whether whole or gutted, should be stored in crushed ice or other cooling medium. The best procedure for handling is as follows: (1) remove the fish from the water promptly after catching; (2) wash trawl-caught fish to remove mud, sand, or debris; (3) sort various species or sizes, as required; (4) remove gills and viscera from larger fish (for example, cod, halibut, and salmon) and wash the fish with clean water; (5) store the fish in sufficient crushed ice or other cooling medium to maintain them at approximately 32° F., allowing for proper drainage in ice and avoiding excessive weight on the fish. If these steps are carried out carefully and promptly, fish of optimum quality are obtained, and subsequent deterioration is minimized. Crowther (1951) pointed out that the secret of fish preservation is to make sure that favorable conditions for bacterial growth, such as high temperatures (those above 32° to 36° F.), do not exist.

For the proper production of fish from an offshore resource, three essentials are necessary: (1) a method of catching the fish, (2) a vessel for transporting the fishermen and fishing gear to and from the fishing grounds, and (3) a means of returning the fish to the dock in marketable condition. As fishing methods have gradually been developed and brought to a high degree of efficiency, the various effects of the fishing methods on the quality of the fish have become recognized. There follows a more detailed account of the principal factors considered of importance in the delivery of fish of optimum quality by the first point of landing by the fishermen.

EFFECT OF FISHING METHODS ON QUALITY

There are two basic commercial methods of catching fish: (1) use of a net to surround or enmesh the fish and (2) use of a hook with bait or an attached lure. These gear may be fished at the surface or in deep water and may be fixed (that is, set at a definite location) or moving. Many variations of each method are used, but over 90 percent of the total fisheries catch is obtained by the use of one or the other. Stansby (1952) has pointed out that methods which permit the least alteration in the fish during the act of catching provide fish of the best keeping quality.

In considering the effects of the fishing method on the quality of the fish, the following are important:

(1) Manner of death. It is well known that an animal killed suddenly and cleanly will be in better condition than will one that dies slowly, possibly struggling a long time in the process. Certain types of fishing gear are superior to others in this respect. In trolling or

in tuna-boat fishing with hook and line, the fish is caught and promptly brought into the boat, where it is killed, bled, and dressed soon after. In a seine or gill net, the fish may become very excited, struggle, and die in a frenzy. Such fish go through rigor mortis prematurely, and a diminished keeping quality is the result.

(2) Interval between time of catch and time fish are removed from the water. If the interval between the time of catching and the time the fish are removed from the water is long, the fish will die before being taken aboard the vessel, and spoilage will have already commenced. With some types of gear, death may occur shortly after catching; for example, the fish in a gill net often suffocate. In the trawl fishery, most of the fish may be dead when brought on deck, owing to crowding of the fish in the net, especially while the net is being raised to the surface of the water and lifted aboard the vessel. If the fish are not crowded in the net, as in a pound net or large seine, they may be held in good condition and removed at a time when they can be handled conveniently or when it is thought to be most suitable. Sardines, for example, are sometimes left in the net until their intestines are empty.

(3) Water temperature. If the fish die in the gear before their removal from the water, the temperature of the water is very important. In southern areas where water temperatures of 75° to 85° F. are common, fish may spoil before they are removed from the gear, in instances of long delay. In the cooler northern waters, where temperatures of 45° to 50° F. are common, the danger of spoilage, if the fish die in the water, is not so great.

(4) Selectivity of gear. With seines, trawls, and gill nets, specific species or sizes of fish may be taken because of mesh-size limitations. The smaller fish of a given species tend to spoil more rapidly than do the larger ones (Stansby 1952): for example, small tuna spoil faster than do large tuna. In trawl fishing, the use of a larger mesh may exclude both young or immature fish and species of small fish of no commercial importance.

(5) Biological factors. Some types of gear, such as that used in salmon trolling, are designed to take fish when they are feeding actively. Other types, such as salmon gill nets, are designed for the same species but are used in locations where fish are not feeding. Considering the effect of sexual maturity, and again using salmon as an example, trolling gear will take fish far from the spawning grounds in the open ocean. Such fish taken by offshore salmon trollers are in prime condition. The same fish taken several weeks later by a gill net at the mouth of a river will no longer be of the same high quality.

Along with the effect of the fishing methods on quality, the differences among the various species or groups of fish in relation to handling problems have also been recognized.

RELATION OF FISH SPECIES TO HANDLING METHODS

As was pointed out in the section on spoilage, the basic characteristics of fish make them highly vulnerable to loss in quality during handling--much more so, for example, than is beef. The resistance of fish to spoilage and the handling and storage methods employed on the vessel vary according to the species and to the particular fishery.



Figure 1.--Dumping a load of groundfish aboard a North Atlantic trawler.

Groundfishes

Cod (Gadus morhua, Gadus macrocephalus), ocean perch (Sebastes marinus, Sebastes alutus), whiting (Merluccius bilinearis), haddock (Melanogrammus aeglefinus), flounder (Pseudopleuronectes and related genera), hake (Urophycis sp.), and pollock (Pollachius virens) are the most important species of groundfish. These inhabit the bottom of the ocean and are caught throughout the year in the New England trawl fishery. Three

of the group--cod, ocean perch, and flounder--are also taken in the North Pacific trawl fishery.

As a group, the fish are similar in that they are lean fish, caught in a trawl, dumped on deck, sorted as to size and species, iced in pens partitioned in the hold of the boat, landed mostly 5 to 12 days after being caught, and usually filleted and skinned for marketing. Some, such as whiting and ocean perch on the Atlantic coast and most bottom fish on the Pacific coast, are iced in the round, whereas other fish in the group are gutted aboard vessel before being iced.

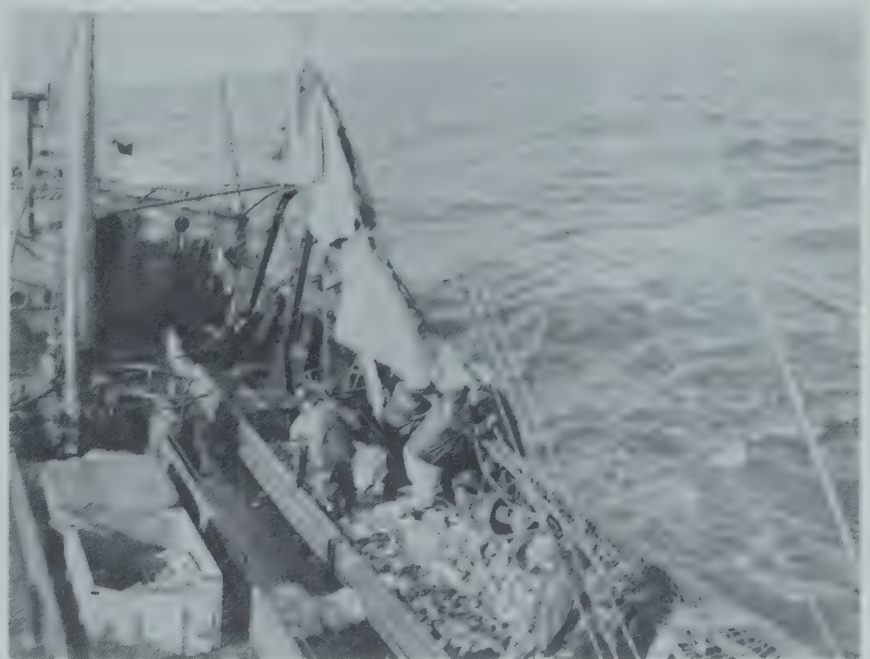


Figure 2.--Putting trawl bag back over the side after discharge of a load of groundfish.



Figure 3.—A load of groundfish aboard a North Atlantic trawler. The fish are ready for sorting, dressing, and icing.

Feeding activity and sexual maturity of the fish at the time of catching influences the quality and the handling methods. For example, "feedy" fish must be gutted shortly after being caught, to minimize softening of the belly wall. Since small fish tend to lose quality more quickly than do large fish, the small fish require a higher ratio of ice. They are placed in separate pens or in the top iced layers to minimize crushing and excessive shrinkage. This practice of icing small fish separately is especially true of scrod had-dock and cod.

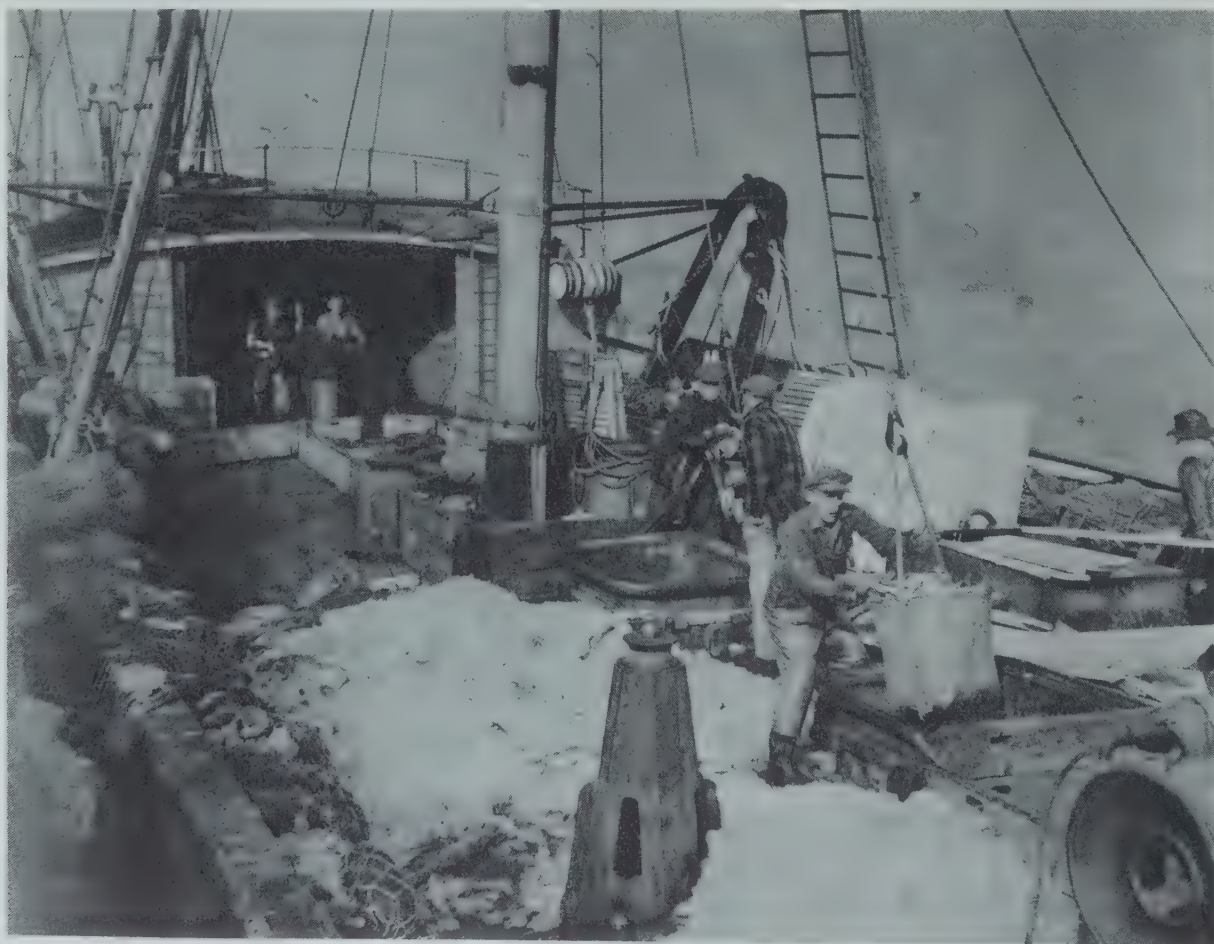


Figure 4.—Unloading groundfish from a North Atlantic trawler. Note that the ice is removed along with the fish and that the pen boards have been removed and stacked on deck to be washed.

Hake and pollock are softer in texture as compared to cod and had-dock, and will not keep as well in crushed ice. On the Pacific coast, hake and arrowtooth flounder are two species not commonly fished, because of their soft texture and of their poor keeping quality. Only a few species of Pacific rockfish are taken, since most rockfish species have poor keeping quality in frozen storage.

Occasionally unknown environmental conditions on certain fishing banks greatly affect the quality of the fish, and the fishermen must either move to other banks or risk taking a loss in their catch. Several of these conditions along the Pacific coast are chalky halibut; slimy or soft-bellied sablefish; greenish-colored flesh in pointed-nose flounder; occurrence of abnormal flavors, like iodoform, in flounder; and excessive numbers of parasites or flesh worms in cod and rockfish. Both the fishermen and the fish buyers recognize these special quality problems, which are minimized by inspection both aboard vessel and ashore.

Halibut

Although properly a member of the groundfishes, the Pacific halibut (Hippoglossus stenolepis) deserves separate mention because the fishery differs in major respects. The halibut are large fish, ranging to over 80 pounds, and are found in the cold bottom waters of the North Pacific. In accordance with regulations of the International Pacific Halibut Commission, halibut are caught only on baited long lines laid along the ocean bottom and cannot be taken by means of a trawl. The seasons and area catch limits are regulated yearly. The halibut, after being caught on a long line, are brought over the rail of the fishing vessel, taken off the hook, and then placed in the "checker" on the deck for dressing. The belly wall is slit, the viscera are removed, the gills are cut away, and the halibut, with the head and nape still intact, are passed into the hold for icing.

Ice is packed in both the belly and gill cavities after which the fish is laid on a bed of ice in the bin so that the water from the melting ice will flow around and away from the fish. It is important that the fish be laid so that any water in the belly cavity drains away from the fish and does not form a pool of blood and slime along the dorsal part of the cavity. Otherwise, halibut become sour smelling. Ample ice is placed around the halibut, with care being given to provide extra ice adjacent to the sides of the vessel and to the pen partitions. This practice avoids exposure of the halibut to the air as the ice melts.

Sablefish

Sablefish (Anoplopoma fimbria), which are another of the species of groundfish, are caught in the North Pacific along with halibut. Sablefish, however, differ from other commercial species of groundfish,

in having a high oil content. The sablefish are dressed and iced in the same way as are halibut except that the head, which is large, is cut off. Although rich in oil, sablefish keep well in ice, showing but little tendency to become yellow and turn rancid.

Salmon

Pacific salmon (*Oncorhynchus* sp.) are caught by means of seines, gill nets, traps or pound nets, and trolling gear. Normally, the salmon taken by seines or nets are caught fairly close to the cannery or cold storage and therefore ordinarily require no refrigeration aboard the vessel. As is discussed later, the use of refrigerated sea water has been tried successfully for holding cannery salmon, where more than a day's delay is involved in delivery of the vessel's catch to the cannery.



Figure 5.—Removing salmon from a drift gill at the mouth of the Stikine River in southeastern Alaska.

Trollers, on the other hand, fish commonly for a week to 10 days for their king and silver salmon catch, and handling and icing is an



Figure 6.--Unloading salmon taken by purse seine gear near the San Juan Islands in Washington. Since these salmon were caught close to the cannery, refrigeration was not necessary.

important part of their job. As the salmon are taken from the water, they are stunned by a sharp blow on the head and are lifted into the boat with a gaff hook. The salmon, soon after being caught, are bled and gutted, and the gills are removed, leaving the nape uncut just below the pectoral fins. This procedure keeps the belly walls closed during handling and icing, and minimizes unnecessary exposure to air. A blunt implement is used to remove the kidney or blood clot, which lies below the backbone in the belly cavity. Excess blood is wiped away, and the salmon are iced similarly to halibut, using ice in the belly and gill cavities with ample ice outside and placing the salmon to allow free drainage of water, blood, and slime away from the fish.

It is important that exposure of the salmon to air be prevented by protecting them with melting ice; otherwise, yellowing of the cut belly flesh and flesh around the nape will occur. Larger king salmon (from 15 to 40

pounds) must be handled with special care to avoid breaking the flesh along the backbone and to keep the skin and scales intact. This careful handling is important if the salmon are to meet the grade standards of the high-priced mild cure salmon destined for later smoking.

Tuna

Only a relatively small amount of tuna is iced aboard vessel, as most tuna are caught far offshore by bait boats and must be frozen for preservation during a trip of 2 to 3 months. Handling and freezing of tuna at sea aboard bait and seine boats are discussed in section 1, Fishery Leaflet 430.

Tuna caught closer inshore by the trollers are often iced for 1 to 2 weeks before being delivered to the cannery. The tuna for cannery use are not bled or gutted. After being caught, they are left on deck until a slack in the fishing intensity allows time for icing. The best practice is to keep this delay to a minimum and to less than 6 hours in any case. Many boats have their holds partly cooled with overhead refrigerated coils or plates to lessen losses in ice during warm weather or long trips. The use of mechanical refrigeration as an ice auxiliary is discussed later in this section.

GOOD "HOUSEKEEPING" ABOARD THE VESSEL

Fish buyers know from experience that, under comparable conditions, the cleanest boats bring in the best quality fish. "Good housekeeping" aboard the vessel is associated with careful handling methods because the fisherman who keeps the fish hold, gear, and deck clean is apt to be quality-conscious when he comes to icing his fish. Contamination from any source will affect fish quality. Dirt, slime, fuel oil, rust, grease, blood, scales, and bits of viscera and flesh must be removed and washed away constantly in order to keep the deck and the hold clean.

The problem of sanitation and housekeeping aboard a boat depends greatly on its design and construction. A little thought and work during the off season can often be used to good advantage for the improvement of sanitation on many older boats. The use of concrete, mastic, or metal (corrosion-resistant types) to eliminate the hard-to-clean corners in the hold saves many hours of labor and cleaning during the busy season. In recent trials, aluminum alloys have been found satisfactory for construction of the lining, stanchions, shelves, and pen boards in the holds of large trawlers (Plummer 1950). On sound wood, there is no substitute for a smooth paint job, using one of the many improved marine finishes now available. To avoid a sour-smelling hold, soft or "logy" wood should be replaced or repainted. Bilges should be cleaned frequently during the fishing season, using a good detergent or bilge-cleaning compound to remove accumulated dirt, oil, and slime. Pen boards should be scrubbed and allowed to dry after each trip. Metal pen boards of corrosion-resistant aluminum have been introduced and save much effort

in maintenance, although the higher initial cost compared to wood must be considered.



Figure 7.—The fish bins in the hold of a North Atlantic trawler after the fish have been taken ashore. Note the removable pen boards on the transverse partition. The smooth liner in this vessel makes it easier to wash down the hold after the fish and ice have been removed.

Deck areas used for sorting and cleaning fish should be scrubbed frequently. If possible, the sorting deck should be used only for fish and not for deck gear because fish thrown against rough corners or projections will bruise and blood clots in the flesh will result. Nets, lines, and miscellaneous fishing gear should be cleaned and preserved properly, not only as a matter of housekeeping, but also to insure long life for the gear.

Although the cold-storage plants prepare the ice from clean potable water, ice can be contaminated with dirt or bacteria during crushing and delivery at the dock and during handling aboard the vessel. Since the ice comes in intimate contact with the fish, it must be kept clean. Shovels and scoops should be cleaned at frequent intervals, and gloves should be washed often and rinsed in chlorinated water if used over long periods.

Personal cleanliness on the part of the fisherman is essential. As a primary handler of a food product, he bears great responsibility.

SORTING, DRESSING, AND WASHING FISH ON DECK

In the troll and set-line fisheries, sorting is continuous as the fish come over the rail. If the catch is plentiful, the fish are placed in checkers according to size or species and held until there is a lull in the fishing, when the fish can be dressed and iced. These fish are generally handled quickly, and the delay on deck is of only short duration.



Figure 8.—Bringing a king salmon aboard a troller in southeastern Alaska. Note the "checkers" or sorting bins immediately in front of the fisherman.

In the trawl fishery, sorting is often a problem, since the fish are caught in large quantities and are dumped all at one time on the deck. Such items as logs, starfish, scrap fish, shells, and mud are often included with the desired fish. In addition to the sorting of the market fish from the unwanted material, different species and sizes are separated for icing. Since small fish are more difficult to keep in good condition than are large ones, the small fish are commonly iced in separate pens. Some species of trawl fish such as hake and pollock are soft, and they spoil more readily than do other species of a comparable size. Thus, they should also be iced separately.

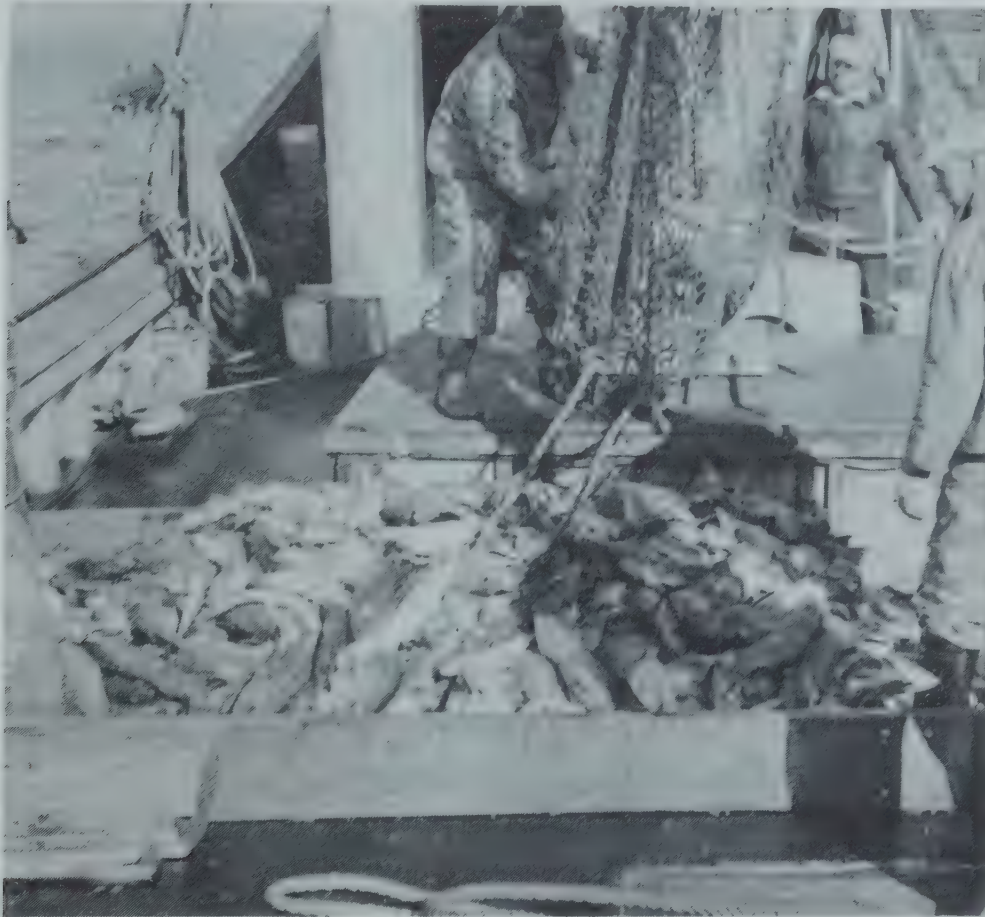


Figure 9.—Dumping a catch of mixed bottom fish aboard a trawler off the Oregon coast. The catch is mostly rockfish.

If the fish have considerable mud or debris on them, they are usually washed with clean water, preferably drawn by pump while the vessel is running. Harbor water should not be used, since it is often contaminated with oil, sewage, or garbage. During the sorting and washing operations, many of the fish will still be alive, and care should be taken not to bruise them. In any case, the fish should not be stepped on or thrown bodily. The use of a chute to transfer the fish to the hold is preferable and eliminates dropping them. The fish, after death, are not as susceptible to

bruising, but they still must be treated with care to minimize crushing or tearing of the flesh. Pews, forks, and fish hooks are handy for sorting fish, but they must be used with skill. The fish should be pewed only in the head, since a hole in the flesh introduces slime and bacterial contamination. The flesh under the skin of live healthy fish is almost free of bacteria, and any contamination introduced after landing will therefore shorten the storage life of the iced fish. For this reason, it is better to sort the market fish by hand whenever practical.

If a delay between the time the fish are landed and the time they are iced is unavoidable, care should be taken to see that the fish are protected from spoilage. If the sun is shining and the deck is hot, for example, the fish should be either covered with a tarpaulin or kept cool and wet with clean sea water. When the fish are iced, small fish and the more perishable species should be handled first.

The following factors are important in determining whether or not the fish should be dressed:

(1) Time between catching and landing. Fish held for more than a few days in ice are usually dressed. With fish that spoil readily or with those that are feeding actively, the fish should be dressed immediately; otherwise, softening of the belly wall (belly burn) may be very rapid. This softening is caused by the stomach enzymes, which remain highly active after the death of the fish.

(2) Size. Large fish, in comparison with small ones, require less time to dress per unit of weight, and fewer are usually caught for a given day's operation. Small fish are tedious to dress by hand and, in many cases, are impractical to eviscerate because of the great number in the catch. Large fish cool slowly in ice, and dressing exposes more area to the cooling effect. Hence dressing becomes a matter of cooling efficiency as well as preventing belly burn.

(3) Industry requirements. Many plants prefer fish in the round, since automatic machinery is used for the dressing and washing operation.

(4) Economics. The economic return to the fisherman may not justify the extra labor of dressing. In some cases in the past, the demand for the fish has exceeded the supply. Under these conditions, buyers have been reluctant to insist on extra measures in handling.

At present, custom dictates the practice in some fisheries. Large buyers or companies may specify the handling procedures, including dressing. Especially in the trawl fishery, the practice varies from one section of the world to another, depending on local custom, regulations, or buyer's specifications. After the fish are dressed and before being iced, they should be washed free of blood with clean sea water. In some fisheries, this preliminary washing is omitted, since the fisherman believes that the subsequent bathing action of the melting ice during stowage in the hold removes the blood and superficial slime. This belief is not entirely correct, even for properly iced fish. Studies with gutted cod on the Atlantic coast (Dyer, Dyer, and Snow 1947), for example, have shown that the muscle along the backbone becomes contaminated both from the skin and from the large blood vessel or kidney lying just below the muscle, next to the belly cavity. Thorough cleaning and washing of the gut cavity reduce the extent of this contamination and minimize the rapid growth of bacteria. This decrease in bacterial growth in turn helps materially to improve the quality of the landed fish.

FRESH-WATER ICE

Keeping Time

One of the most important facts to bear in mind concerning the use of ice for preservation of fish is that spoilage is only retarded, not stopped. Under proper conditions of handling, fish such as prime halibut may be preserved in ice for 8 to 12 days before a noticeable lessening in quality occurs. Cod similarly iced will keep well for over 7 days. On the other hand, bottom fish left on deck for 12 to 18 hours and iced improperly in a deep hold without the use of shelf boards may show appreciable loss in quality after only 4 to 5 days.

How Ice Aids in Preservation

Ice, when properly used in adequate amounts, aids in preservation in two ways: (1) the temperature of the fish is lowered to approximately 32° to 36° F., which slows the bacterial and the enzymatic changes; and (2) the melting of the ice bathes the fish in clean cold water and, with proper stowage, washes away considerable slime, blood, and bacteria. The resulting contaminated water accumulates in the bilge of the boat and, at intervals, is pumped overboard.

Insulation

Every pound of ice, on melting, absorbs 144 B.t.u. of heat from its surroundings. This absorption of heat is sufficient to lower the temperature of 19 pounds of fish 10 degrees Fahrenheit (assuming that the fish has a specific heat of 0.760 and that no external heat were absorbed in the process). In actual practice, the heat transfer from the boat hold and air equals or exceeds the heat transfer from the fish. Dunn (1946) showed that, on a 6-day trip, the heat gained by a trawler hold with a capacity of 100 tons of fish and 30 tons of ice caused about the same amount of ice to melt as was required to cool the fish. This transfer of heat demonstrates the desirability of insulating the hold, which would make possible the saving of a substantial quantity of ice during long trips.

Ice Contamination

Chlorination is recommended for treatment of the water at the ice plant to insure that only sterile ice is produced. Unfortunately, during storage, crushing, and handling, ice can become contaminated with bacteria, which in turn contaminate the fish and accelerate the bacterial spoilage (Castell and Triggs 1953). In addition, ice becomes contaminated in the hold from the drainage of fish packed above it. For this reason, unused ice should be discarded at the end of the trip, and the hold should be washed before new ice is loaded.

Subcooling

In the best practice, ice is subcooled to about 0° to 10° F. during cold storage at the ice plant. Such ice on being crushed, breaks cleanly, and the resulting crushed ice is sized, from irregular chunks an inch or two across to fine grains. This subcooled crushed ice flows freely and is easily loaded into the separate pens or sections of the fish hold. One or two pens are usually left free so that they may be used to ice the first fish of the trip. The ice is shoveled or scooped from one pen to another as needed. It is important that the ice flows freely even after 5 to 10 days in the hold. Properly sized ice loaded at a temperature of 5° F. will melt around the outside and form a crust; however, the ice, on being broken through, is found to be loose and easily handled and well below the melting point. This subcooled ice lasts longer than does ice at 32° F., under comparable conditions. In a few geographical areas, crushed ice is delivered to the fishing boat at a temperature very close to the melting point (32° F.). Such ice tends to fuse into a solid mass and is more difficult to use.

Particle Size

Since both close contact with the fish and drainage through the ice are necessary, the ice must not be too coarse or too fine. With too finely crushed ice, slime and water tend to accumulate through it in layers. On the other hand, large chunks are undesirable, for they yield poor contact cooling of the fish. Also, they bruise and mar any tender skin or flesh pressed against them. If the ice is prepared from blocks, a crushed ice with graduated particle size is best.

In recent years, flake ice prepared by continuous freezing of a film of water on a refrigerated drum has proved very satisfactory. The ice consists of irregular flat plates. Such ice is convenient for use in that it requires no crushing for delivery and that it may be precooled to 0° F. and stockpiled in the flake form. Flake ice tends to be a little bulky and, if not confined with pen boards, to shift in the hold. Drainage and cooling characteristics of this ice are as good or better than are those of crushed ice; however, precooling well below 32° F. is especially important with flake ice to minimize its tendency to fuse into a solid mass.

Ratio of Ice to Fish

Every fisherman soon learns how much ice to "take on" in order to carry him through a trip. The expected duration of the trip, the temperature of air and sea water, the insulating value of the sides and deck head of the vessel, and the expected quantity of fish to be obtained are all factors to be considered in estimating the amount of ice to be loaded. Ice is cheap compared to the other expenses of a fishing operation; hence no fisherman should cut short his estimated need. The exact ratio of weight of ice to weight of fish to be carried varies commonly from 1:4 to 1:1. In northern waters in uninsulated holds of wooden vessels, a ratio of 1:2 is common. Recent studies showed that more rather than less ice

should be taken by fishing vessels because it was found that additional ice (compared to present practice) should be allowed at the sides of the vessel and adjacent to the wing boards of each pen. Any exposure of fish at these points due to melting of ice contributes substantially to quality losses.

Correct Icing

To correctly ice the fish in the hold, three things should be accomplished: (1) the fish should be placed with sufficient ice around them to cool them as promptly as possible and to maintain their temperature as close to the melting point of the ice (32° F.) as is practical for the duration of the trip; (2) the ice and fish should be arranged to allow accumulated water, blood, and slime to drain through the mass into the bilge; and (3) the fish should not be subjected to great pressure from the weight of fish and ice placed above; otherwise, the physical damage as well as the shrinkage or loss of weight by the fish will be excessive.

Correct icing requires considerable care and experience, and every vessel is a separate problem depending on the construction, hold and pen layout, and the relative heat transfer from the water and air outside the hold. Knake (1946), in discussing the correct icing of fish at sea, has pointed out that from 50 to 60 percent of the profit of a trip may be lost if the quality of the catch is reduced through inadequate or incorrect icing. Ample ice should be placed on the floor of each pen, 8 to 12 inches deep, for a trip of 8 to 12 days. A like amount should be placed at the skin of the vessel and on top of the fish. A smaller amount should be used at the wing boards (the transverse partitions) and sides of each pen to keep the fish from contacting the board. For eviscerated fish, the gut cavity or poke of the fish should be well filled with ice, taking special care to pack the ice in the gill cavity and around the nape. Preferably, each fish should be surrounded by ice or the fish placed in alternate layers such that the ice is in actual contact with the greater portion of each fish.

The practice of using a bed of ice, then layering 10 to 12 inches of fish, followed by a thin layer of ice and another thick layer of fish results in most inefficient cooling. Two to three days may be required, in this case, to lower the temperature of the fish to 36° F. In some instances, improperly iced fish does not cool appreciably throughout the entire period of storage. Under proper conditions, however, not over 3 to 6 hours should be required to lower the temperature to 36° F. of fish weighing about 5 pounds.

Fish should be placed on a rounded layer of ice so that the melt water drains away from the fish to the sides of the pen. In placing the fish on the ice, the belly cavity should be turned in such a manner that there will be adequate drainage from it. A good icing job has been done if, at the end of the trip, sufficient ice remains on the bottom and at all sides so that the entire load has been maintained at

a temperature not higher than 36° F. (or 32° F., ideally).



Figure 10.--Unloading a catch of bottom fish from a trawler at a Seattle dock. Note pen with remaining ice and fish in the hold.

Fish do not freeze at one point in the temperature scale, as water does at 32° F. Rather, they begin to freeze at about 30° F. and gradually harden as the temperature drops. At 23° F., the fish have passed through the zone of maximum ice-crystal formation but are still not solidly frozen. The lower freezing range of fish means that an ice melting at a lower temperature than 32° F. can be utilized to lower the holding temperature further.

SALT-WATER ICE

Tests on the effect of temperatures close to that of freezing on the storage of fish (Castell and MacCallum 1950) showed that a reduction in the temperature of the fish from 37.0° to 31.5° F. increased their keeping time in ice as much as did a temperature reduction from 77.0° to 37.0° F. The lower temperature of the fish was obtained through the

use of salt-water ice (about 3 percent sodium chloride), which has a melting point of approximately 28° F. Salt-water ice is best prepared by the flake-ice method in order that the salt may be distributed uniformly through the ice. In a pilot-plant study, subcooled flaked salt-water ice and ordinary crushed fresh-water ice were used in icing similar lots of fish, both held under otherwise similar conditions of storage (Field 1953). The flesh temperatures of the salt-water-iced fish ranged from 30° to 32° F., which was 6 degrees lower than the temperature range of the fish iced with crushed fresh-water ice. The fish stored in the salt-water ice were superior in quality at the end of the test.

BACTERICIDAL ICE

In efforts to improve the keeping quality of fish in ice, experimenters have incorporated a number of preservatives or germicides in the ice. Sodium benzoate, benzoic acid, chloramine compounds, fumaric acid, sodium hypochlorite, sodium nitrite, carbon dioxide, hydrogen peroxide, calcium propionate, disodium phosphate, and various antibiotics are among the many substances tried (Tarr 1946). Generally speaking, the best of the germicidal ices produced a very minor improvement in keeping quality. Their use has not become widespread because of their limited value and the extra cost to the fisherman. More recent experiments by Boyd, Brumwell, and Tarr (1953) on the use of the antibiotic aureomycin in ice have shown that, in quantities of 2 to 4 parts per million, aureomycin ices effected a very marked improvement in keeping quality of dressed lingcod during storage for a period of 15 days in ice.

In planning the use of any preservative or germicide in the icing of fish, the potential user should bear in mind that any such substance must meet the approval of the U. S. Food and Drug Administration for use with food products. At present, few additives have been approved by that agency. Proper care in the handling and storage of fish, with adequate amounts of ordinary crushed or flaked ice will yield as much or more improvement in keeping quality than will the casual use of any preservative-treated ice tested and accepted for use with food fish to date. Any bactericidal ice that has been accepted for use on fish will be of greatest value only if its use is combined with the best handling practices.

MECHANICAL REFRIGERATION AS AN ICE AUXILIARY

For extended trips, mechanical refrigeration of the fish hold for keeping ice on the outbound trip without loss by melting has been quite successful. The principle is simple in that only enough refrigeration need be supplied to absorb the heat entering the hold through the sides of the vessel and through the deck head. The actual freezing of the fish is not intended, as once the fish are iced, the refrigeration is turned off or set above 32° F. so that the normal melting of the ice will cool the fish.

This use of mechanical refrigeration, to yield best results, must be combined with 4- to 6-inch-thick insulation in the hold. In some cases, the reduced requirement for ice results in an increased stowage capacity of the hold for fish. On the Pacific coast, one such successful installation on an 82-foot halibut boat has been reported (Anonymous 1950). The use of mechanical refrigeration, according to the owner, not only allowed the boat to stay out longer but also assured fish of better quality than had previously been found with the fish that were protected by ice alone on shorter trips made prior to the use of the mechanical refrigeration.

In this type of installation, no attempt should be made to freeze the fish, and the stored ice should be allowed to melt and supply the refrigeration needed to cool the fish to 32° to 35° F. The melting of the ice not only provides proper cooling but also provides the moisture and the bathing action so essential in retaining the freshness of the fish. Cutting (1949) reported that, in careful laboratory tests, it was found that the rate of cooling of fish (from 55° to 33° F.) packed in ice was independent of temperature of the surrounding air (from 27.5° to 55° F.). Therefore, the only advantage of refrigerating the hold of a boat using ice is to conserve the ice.

OTHER METHODS OF HOLDING FRESH FISH ABOARD THE VESSEL

Refrigerated Sea Water

The cooling of fish in circulating chilled sea water at 32° F. is more efficient than is cooling in crushed ice (Konokotin 1949). In icing fish aboard the vessel, the best results are attained if ice completely surrounds each fish. In practice, this ideal icing is difficult to attain, and a layer of fish tends to build up through which the melt water from the ice percolates. The cooling medium in the case of circulating refrigerated sea water surrounds the fish entirely, and thus the transfer of heat from the fish is more rapid in the chilled sea water. Moderate circulation of the chilled sea water through the mass of fish and past the cooling coils can be adjusted to achieve a uniform temperature of 32° F. (or lower if desired) at all times. The sea water excludes free air from around the fish and there is less opportunity for oxidation of the fish surface, as often occurs in the surface fat of fish held for long periods in ice.

Refrigerated sea water or dilute brine has long been used in holding sardines and herring at the shore plants prior to processing. Sigurdsson (1945) stated that herring stored in refrigerated brine at 32° F. showed superior keeping quality to those held either in crushed ice or in air at 32° F. Konokotin (1949) demonstrated that sprats could be cooled more efficiently in refrigerated sea water than in crushed ice. Studies with Gulf of Mexico shrimp (Higman, Idyll, and Thompson 1954) showed that shrimp held in sea water chilled to 29° to 32° F. were superior from the standpoint of flavor and appearance to those held in crushed ice.

Recently, tests by two salmon-canning firms in holding Pacific salmon in refrigerated sea water have shown considerable promise, and one firm has installed refrigerated sea-water tanks aboard a barge for the purpose of holding salmon for several days at the cannery or during several-day trips to the fishing grounds where fish are purchased. A 42-foot salmon trolling boat, fishing in Alaska, was converted during the past year and successfully used refrigerated sea water for holding fresh king salmon. The canners have found that the use of refrigerated sea water for holding salmon has reduced weight losses (Bloomberg 1955).

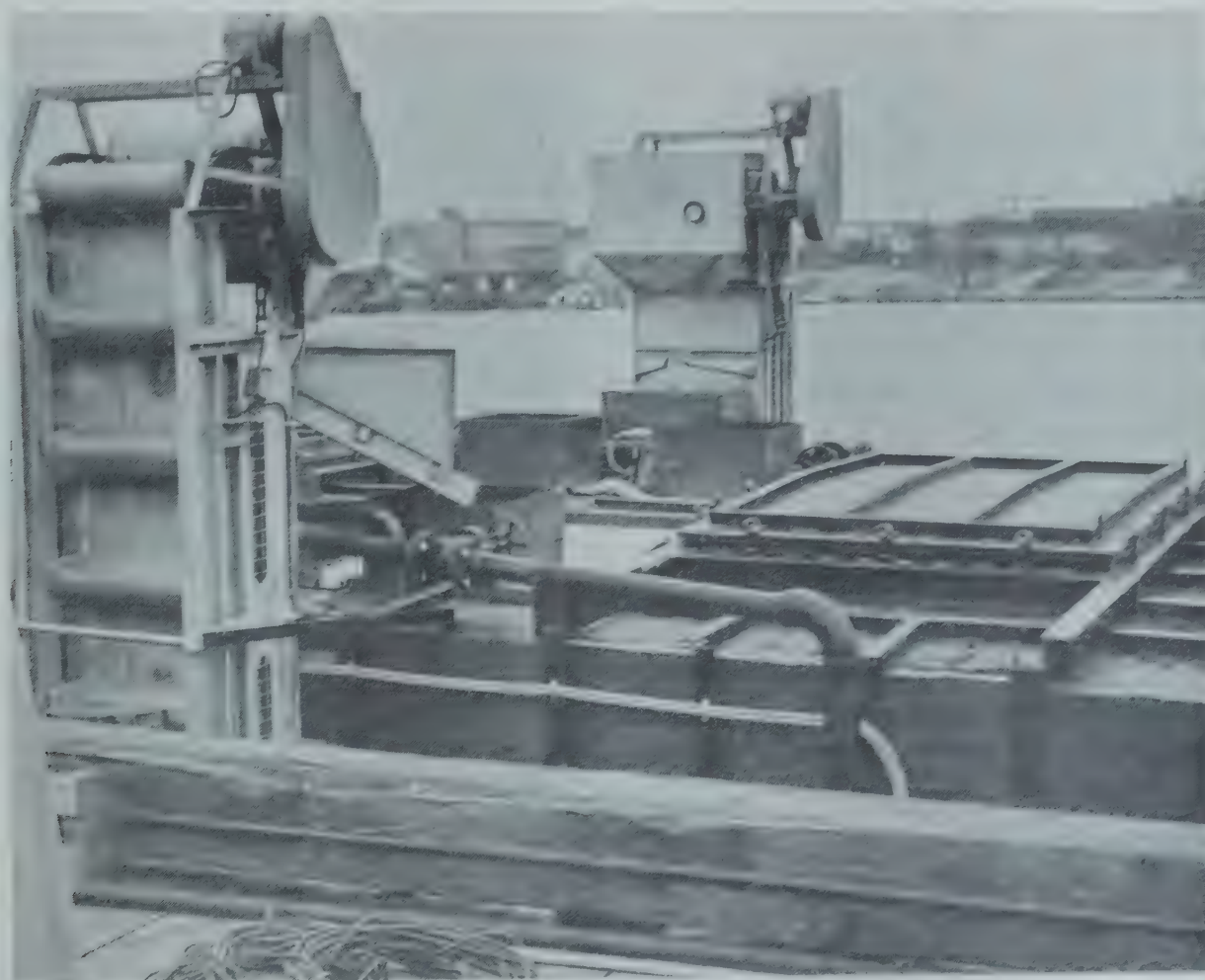


Figure 11.--Barge with refrigerated sea-water tanks for holding salmon. The elevators are used to raise the salmon and chute them into the tanks through the built-in "chimneys." (Photo courtesy of Pacific Fisherman)

The problems of refrigerating a hold for sea-water storage are somewhat greater than are those for ice storage, as the hold must not only be constructed water-tight but must be subdivided into sections or tanks with suitable baffles. Large centrifugal-type pumps are needed for pumping water in or out of the separate tanks and to and from the brine chiller or heat exchanger. Special equipment must be designed for discharging and unloading the fish. The water in the tanks is precooled to about 29° F. prior to being loaded with fish. Ice may be carried to supply additional refrigeration if large volumes of fish must be handled

in a short time. If preferred, 3 percent of salt (0.25 pounds of sodium chloride per gallon of water) may be used instead of sea water.

Live Wells

Crabs and lobsters cannot be held in ice satisfactorily, yet they must be delivered to the shore plant alive. For this purpose, the hold of the fishing vessel is flooded with sea water in which the crabs or lobsters can be kept alive and healthy for 3 to 4 days. With crabs, the sea water is circulated continuously to keep them in good condition.



Figure 12.--Unloading live dungeness crabs from the well of a crab boat at Ketchikan, Alaska.

If the crabs are held in the same water for more than a few hours, however, the water should be aerated. The installation of baffles or tanks is necessary if the boat is to be operated safely with the hold full. During rough weather, vessels that have the entire hold flooded may experience difficulty. In actual practice aboard the vessels used in the dungeness

crab fishery on the Pacific coast, the vessels do not usually run with the hold full of water. Sea water is pumped in and out at sufficient intervals to keep the crabs cool and moist. Fortunately, they can survive several hours out of water. After 3 to 4 days of this treatment, however, dungeness crabs tend to lose weight and become sluggish. Recently, king crabs have been successfully transported from Alaska to Puget Sound ports in vessels equipped with live wells.

Lobsters may also be handled in live wells, although it is necessary to plug their claws in order to prevent them from maiming one another. With careful handling, lobsters may be held alive for short periods in moist air at not over 50° to 55° F. Moss (1952) reported that a new method of carrying lobsters alive in portable wet-tanks in the dry hold of the vessel was satisfactory, even in heavy weather and over long hauls. The portable tanks were arranged in the hold in such a manner that water pumped into the top tanks of each bank overflowed into the lower tanks and then into the bilge, from which it was pumped overboard. The water in each tank was controlled at the proper level by standpipes, which maintained enough water to keep the lobsters alive.

LITERATURE CITED

ANONYMOUS

1950. Mechanical refrigeration effective for halibut. Pacific Fisherman, vol. 48, No. 3, February, p. 63.

BLOOMBERG, RAY

1955. Reefer tanks keep fish fresh, cut weight loss. Food Engineering, vol. 27, No. 9, September, pp. 111 and 159.

BOYD, JOHN; BRUMWELL, C.; and TARR, H. L. A.

1953. Aureomycin in experimental fish preservation. Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Stations, No. 96, October, pp. 25-28.

CASTELL, C. H., and MAC CALLUM, W. A.

1950. The value of temperature close to freezing on the storage of fish. Journal of the Fisheries Research Board of Canada, vol. 8, No. 2, May, pp. 111-116.

CASTELL, C. H., and TRIGGS, R. E.

1953. Contaminated ice in the boats at sea. Fisheries Research Board of Canada, Progress Reports of the Atlantic Coast Stations, No. 55, March, pp. 24-26.

CROWTHER, H. E.

1951. Control of fish spoilage by icing and freezing. Commercial Fisheries Review, vol. 13, No. 3, March, pp. 6-10. Also Sep. No. 274, Fish and Wildlife Service, Department of the Interior, Washington 25, D. C.

CUTTING, C. L.

1949. The cooling of trawler's fish in ice. Report of the Food Investigation Board (Great Britain) for the year 1939, pp. 41-42.

DUNN, A. F.

1946. Heat transfer in trawler holds. Fisheries Research Board of Canada, Progress Reports of the Atlantic Coast Stations, No. 36, December, pp. 3-6.

DYER, W. J.; DYER, F. E.; and SNOW, J. M.

1947. The spoilage of gutted cod stored in crushed ice. Fisheries Research Board of Canada, Progress Reports of the Atlantic Coast Stations, No. 37, January, pp. 3-7.

FIELD, CROSBY

1953. Recent experiments show value of flaked ice frozen from salt-water ribbons. Fishing Gazette, vol. 70, No. 8, August, pp. 54-55.

HIGMAN, J. B.; IDYLL, C. P.; and THOMPSON, J.

1954. Holding fresh shrimp in refrigerated sea water. Southern Fisherman Yearbook, vol. 14, March, p. 95.

KNAKE, BORIS O.

1946. Icing of fish at sea. Fish and Wildlife Service, Washington 25, D. C., Fishery Leaflet 189, July, 3 pp.

KONOKOTIN, G.

1949. Cooling and preserving fish in sea water and in tannin solutions. Kholodilnaja Technica (Russian), vol. 26, No. 2, April-June, pp. 66-69. Abstracted in Refrigerating Engineering, vol. 57, No. 12, December, pp. 1186-1187.

MOSS, FRANK T.

1952. New system of portable wet tanks stops lobster losses.
Maine Coast Fisherman, vol. 6, No. 12, July, p. 5.

PLUMMER, H. C.

1950. Aluminum holds protect fish. Food Industries, vol. 22,
No. 5, May, p. 121.

SIGURDSSON, G. J.

1945. Studies on the storage of herring in refrigerated brine.
Proceedings of the Institute of Food Technologists,
pp. 91-114.

STANSBY, MAURICE E.

1952. Handling fresh fish. Fishery Leaflet 115, Fish and
Wildlife Service, Department of the Interior, Washington
25, D. C., February, 4 pp.

TARR, H. L. A.

1946. Germicidal ices. Fisheries Research Board of Canada,
Progress Reports of the Pacific Coast Stations, No. 67,
pp. 36-40.

SECTION 3

HANDLING FRESH FISH AT THE SHORE PLANT

By C. J. Carlson, Chief, Fishery Products Laboratory; Joseph Carver, Fishery Products Technologist; and Martin Heerdt, Chemist*

TABLE OF CONTENTS

	Page
Good housekeeping practices	42
Plant construction	42
Coverings and drains	42
Lighting and ventilation	43
Restrooms	43
Provisions for cleaning	44
Provisions for rodent and insect control	45
Plant equipment	46
Plant management	47
Grading fish and shellfish for quality	48
Fish	48
Shellfish	49
Diversity of methods of handling fish and shellfish	49
Preparation of round and dressed fish--handling of fresh-water fish as an example	50
Methods of unloading fish from vessel to shore plant	50
Handling procedures at the fish house	51
Preparation of fish for use in the fresh-fish trade	52
Handling procedures for certain species	52
Preparation of fillets--handling of New England groundfish as an example	54
Methods of unloading fish from vessel to processing plant	54
Plant storage prior to processing	57
Recommendations for controlling quality before processing	57
Preparation of fillets	57
Filleting by hand	58
Filleting by machine	60
Preparation of frozen steaks--handling of halibut, salmon, and sablefish as examples	62
Why certain species of fish are frozen for steaking or filleting	62
Steaking and packaging frozen fish	63
Halibut steaking	63
Halibut packaging	65
Salmon and sablefish steaking	67
Salmon and sablefish packaging	67

* Ketchikan, Alaska; Fishery Technological Laboratory, East Boston 28, Massachusetts; and Fishery Technological Laboratory, Seattle 2, Washington, respectively.

	Page
Steaking, filleting, and packaging partially thawed fish .	67
Halibut steaking and packaging	67
Halibut filleting and packaging	72
Salmon and sablefish steaking and packaging	73
Salmon and sablefish filleting and packaging	73
Handling of fish frozen at sea--processing of tuna at the cannery as an example	73
Arrangement of tuna plant	73
Conveyor systems for carrying tuna to the plant	74
Methods of thawing frozen tuna	75
Subsequent processing steps	76
Handling of shellfish preliminary to processing	76
Shrimp	76
Lobster and crab	79
Clams	79
Oysters	80
Scallops	80
Recommendations for the control of quality at the shore plant	80
Fish--before processing	80
Fish--during processing	81
Shellfish	81
Literature cited	82

ILLUSTRATIONS

Figure 1.--Well designed equipment for unloading salmon . . .	47
Figure 2.--Dipping smelt from net in winter	50
Figure 3.--Removing lake herring from trap net and placing them in boxes	50
Figure 4.--Unloading lake herring at the shore plant	51
Figure 5.--Fifty pounds of lake herring	51
Figure 6.--Stacking boxes of iced lake herring in a refrig- erator car	52
Figure 7.--Scaling lake herring	52
Figure 8.--Dressing lake herring	53
Figure 9.--Lake herring (<u>Leucichthys artedi</u>)	53
Figure 10.--Unloading fish from a hold of the ship by the use of a canvas basket and a winch at Boston, Mass. . . .	55
Figure 11.--Dumping fish from a canvas unloading basket into a tared weighing box	56
Figure 12.--Loaded weighing boxes on a tractor-drawn trailer on the way to a processing plant	56
Figure 13.--Filleting ocean perch by hand	58
Figure 14.--Hand filleting haddock	59
Figure 15.--Filleting machine cutting haddock	61
Figure 16.--Typical skinning machine	62
Figure 17.--Line for steaking and packaging frozen halibut. .	63
Figure 18.--Packing line for frozen halibut steaks.	64
Figure 19.--Cuts of halibut steaks	64
Figure 20.--Steaking a frozen halibut loin	65

	Page
Figure 21.--Dicing frozen halibut steaks	65
Figure 22.--Weighing frozen halibut steaks into a carton . . .	66
Figure 23.--Closing cartons filled with frozen halibut steaks and feeding the closed cartons to a wrapping machine	66
Figure 24.--Packing wrapped cartons of frozen halibut steaks into shipping cases	67
Figure 25.--Line for steaking and packaging fresh or partially thawed halibut	68
Figure 26.--Slicing partially thawed halibut	69
Figure 27.--Stainless-steel briner for halibut steaks	69
Figure 28.--Trimming and dicing halibut steaks to size	69
Figure 29.--Trimming, candling, and grading halibut steaks at inspection table	70
Figure 30.--Machine for making cartons	70
Figure 31.--Packing and weighing halibut steaks into 1-pound cartons	71
Figure 32.--Placing wrapped cartons on trays	71
Figure 33.--Loading trays of cartons into a plate freezer . .	71
Figure 34.--Packing cartons of frozen halibut steaks into a shipping case	71
Figure 35.--One-pound packages of halibut steaks	72
Figure 36.--Packaged fillets in carton after metal mold has been withdrawn	72
Figure 37.--A typical layout of a tuna plant	74
Figure 38.--Hoisting baskets from the hold of a shrimp trawler	77
Figure 39.--Tank in which shrimp are de-iced and washed . . .	77
Figure 40.--Unloading boxes of whole shrimp	78
Figure 41.--Submersible live-boxes for holding Dungeness crabs.	79

TABLES

Table 1.--Recommended restroom facilities	43
Table 2.--Suggested concentrations of chlorine solutions for use in fish plants	45

GOOD HOUSEKEEPING PRACTICES

Operators of fish shore plants in the United States and its territories are guided by federal, state, and territorial sanitary codes and regulations that require observance of certain minimum health standards. In general, the aims in good housekeeping at the shore plant are the maintenance of clean facilities and freedom from possible contamination. These objectives can be obtained through (1) proper construction of the plant, (2) efficient design and layout of equipment, and (3) good management.

Plant Construction

Good housekeeping practices with regard to the construction of the plant include such factors as the covering used for floors, walls, and ceilings; drainage; ventilation; lighting; rodent and insect control; personnel restroom and washroom facilities; and provisions for cleaning the plant.

Coverings and drains.--The floors of any fish shore plant should be covered with a hard smooth-surfaced material such as concrete or tile. The construction should be such that the floor is waterproof, watertight, and structurally strong so that cracks do not develop. With this type of floor covering and with adequate cleaning, there is little opportunity for growth of bacteria, for development of their attending foul odors, and for their possible contamination of food. An important factor in the construction of the floor is good facilities for drainage. The floor should be designed with adequate slope (usually $1/8$ to $1/4$ inch per linear foot) so that refuse and liquids can be led easily to the drains. These floor drains should have traps and should be located at convenient intervals, depending on the type of operation and on the load and area they are expected to serve. In all cases, the slope of the floor and the number of drains should be adequate and should meet sanitary codes. In the building of the floor, care should be taken to insure that all floor and wall junctions are rounded off and made watertight. Square junctions, especially corners, are difficult to clean and, in a short time, can present a sanitation and odor problem.

The walls of the shore plant should be watertight, smooth, and painted. Waterproofing should be used on the wall from the floor level to a height of several feet, depending on the type of plant operation. In plant areas where water or fish may be splashed, the entire wall surface should be waterproofed. This precaution insures a dry surface on which bacteria and resulting off-odors do not develop.

Ideally, the ceiling of the shore plant should be completely covered so that foreign material cannot fall from overhead pipes, machinery, and beams. Properly designed modern plants with high trussed roofs and without covered ceilings, however, have been found to be satisfactory.

In smaller plants with low roofs, the ceilings should be covered.

Lighting and ventilation.—Adequate lighting within the plant is necessary for efficient operation. According to Waidelich (1951), fluorescent lighting varying in intensity from 35- to 100-foot candles is usually required. Maximum use should be made of natural lighting by incorporating advantageously located windows and skylights into the design of the building.

There should also be adequate ventilation. The same windows and skylights that allow for natural lighting may be used for this purpose. Exhaust fans or roof vents utilizing natural air currents are sometimes employed to advantage in plant areas where cooking operations are carried out. Blower-type unit heaters may be used to circulate the air in cool climates or during the winter. In warm humid climates, mechanical air-conditioning is the best method for cooling and circulating the air. Before any type of mechanical system of ventilation is installed, however, a competent engineer should be consulted.

Restrooms.—Separate clean restrooms, water-flushed toilets, and washrooms for male and for female employees should be placed in appropriate areas in the plant. Based on the maximum number of employees of each sex hired in a season, table 1 gives the number of separate water-flushed toilets that should be installed for each sex (Anonymous 1947a).

Table 1.—Recommended restroom facilities

No. of persons	Minimum number of toilets
1 to 9	1
10 to 24	2
25 to 49	3
50 to 100	5
Each additional 30	1

The restrooms should be provided with toilet paper, washing facilities, hot and cold water, soap, paper towels, and waste receptacles. These rooms should be well ventilated, should be kept clean at all times, and should be well posted with signs concerning personal cleanliness and hand washing after an absence from work. Some plants provide bactericidal-type liquid or powdered soaps and detergents for use in the washroom. Their use, however, must be accompanied with diligent washing and scrubbing. An excellent plan used in some plants to promote clean restroom facilities is to furnish each employee with a locker, where he may keep personal property and clothing. Care then must be taken to police the restrooms, however, in order that the lockers do not become catch-alls and, in themselves, a sanitation problem.

Provisions for cleaning.--An important point to observe in constructing a plant is to make certain that it is designed for ease in cleaning. Such factors as smooth walls and floors, good ventilation and lighting, and adequate floor drainage have been mentioned previously. In addition to these provisions, water outlets should be located throughout the plant to provide a good supply of clean fresh water. The diligent use of water, cleaning compounds or detergents, scrubbing brushes, special cleaning equipment, bactericides, and manual labor is essential in controlling bacterial contamination.

Because there are many types of detergents, the selection of the right detergents or combination of them for a specific cleaning job is important. In a single plant, three or four types of detergents may be used. Somers (1949) reported that the desirability of a detergent usually is determined by the degree to which it exhibits the following characteristics:

1. High wetting or penetrating action, which effects rapid washing away of the soil.
2. Good rinsibility, which results in the detergent and soil being rinsed from the equipment freely and rapidly after the desired cleaning has been accomplished.
3. High emulsifying power for oils.
4. High deflocculating or dispersing power, to bring deposits or precipitates into suspension so that they can be washed away.
5. Good water conditioning or sequestering properties in alkaline solutions, to prevent deposits, on the equipment, of the calcium and magnesium compounds from the water.
6. Good dissolving and neutralizing power, for the purpose of dissolving or neutralizing tenacious deposits and of saponifying fats to make them soluble in water.
7. Low corrosiveness to the surfaces on which they are used.

Brushes are important tools for cleaning shore-plant equipment and facilities. A variety of brushes for regular cleaning and for cleaning in hard-to-reach places should be used.

Special cleaning equipment such as high-pressure spray units are good tools for use in cleaning. They are effective in removing tenacious slime and other deposits from equipment, and they save considerable hand work. Hot water or hot detergent solutions may be used in these units. (A word of caution: as this equipment operates under high pressures, it should be used with care to avoid damage to equipment or injury to personnel.) Another piece of equipment used to clean floors is the wet pickup vacuum cleaner. Some of these cleaners scrub the floor, rinse it, and then pick up the dirty water.

After the cleaning operation has been completed, the work areas and equipment should be disinfected with a germicide. Chlorine-liberating

compounds have proved to be effective and economical germicides. The concentrations of chlorine solutions shown in table 2 have been suggested for use in fish plants (Anonymous 1947b).

Table 2.--Suggested concentrations of chlorine solutions for use in fish plants

Use	Available chlorine (Parts per million)
Wash water (sea or fresh)	1 to 10
Rinse water for hands	100
Clean, smooth surfaces (washbasins, urinals, glassware)	50 to 300
Clean, smooth wood surfaces (new boxes, new table tops)	300 to 500
Rough surfaces (worn table tops, old boxes, concrete)	1,000 to 5,000

Little information is available concerning the effectiveness of quaternary ammonium compounds as disinfectants in fish plants. Salton (1948), however, has reported that a solution containing 200 parts per million of such compounds was found to be adequate as a sanitizer for utensils in a milk plant, after the equipment was properly washed.

Another method of disinfecting in a large fish plant has been reported by Hurley (1949). In this method, the entire water supply was chlorinated. A chlorine residual of 5 to 10 parts per million was maintained during processing, and a residual of 25 parts per million was maintained during the cleanup periods. The method was effective in reducing the bacterial load throughout the plant.

No plant cleaning program can succeed without the services of good, conscientious, hard-working personnel. They must supply the "elbow grease" and have the pride in their work to see that the job is done well.

Provisions for rodent and insect control.--In constructing the shore plant, the builder should take special precautions for the exclusion of rodents and insects. Rodents are considered to be one of the most serious sources of contamination in the seafood industry (Kaylor 1950). Control can be established by rodent proofing ingredient rooms and by covering windows, doors, and other openings with rustproof metal screens. Clean plant facilities also aid in rodent control by eliminating possible sources of food. Routine inspections of beams for evidence of rat runways or nesting areas should be made.

Dry ice has been used as a successful rodenticide in food plants where rodent infestation has occurred (Anonymous 1952a). The area to be

treated is emptied of food products, sealed off, and sufficient dry ice is placed in the area to produce a concentration of 20 percent carbon dioxide. This concentration should be maintained for at least 12 minutes. The carbon dioxide forces the rodents out of their holes and nests and into the open where they die by suffocation. Since carbon dioxide can kill plant personnel, warning signs should be posted, and workers entering the area should wear oxygen masks until the air is safe.

If serious rodent infestation in a plant requires the use of poison for control, an expert familiar with the proper selection and use of rodent poisons around a food plant should be employed. No untrained person should be entrusted with this highly hazardous job. Should the foods become contaminated, many fatalities could result.

Except for the common house fly, insects are not a major problem in the seafood industry. The screens over windows and other openings for the control of rodents, will also control insects. Clean plant and plant facilities and elimination of breeding places also assist in controlling insect contamination. When the plant interior and exterior are painted, an insecticide that can be incorporated with the paint may be used (Anonymous 1952b). This insecticide is claimed to retain its effectiveness for the life of the paint.

Plant Equipment

Choosing the right type of equipment and making the proper installation are important factors in plant sanitation. The mechanical equipment should be designed so that it can be cleaned thoroughly and easily. Wherever possible, tubular construction should be used in lieu of angular construction. Table tops on which fish are handled should be constructed of a hard nonporous material that will not absorb the juices and refuse from fish. Table tops made of noncorrosive metals, replaceable hardwood cutting boards, and synthetic rubber-thermoplastic materials (Anonymous 1951) have been used with good success. Plain wooden tables are completely unsatisfactory because of the difficulty in cleaning them.

Conveyors should be constructed of metals that are resistant to corrosion and should be so designed that they can be cleaned easily. Construction that will result in hidden corners and recesses should be avoided. The carrying surface of conveyors should be constructed of such nonabsorbent materials as rubber or metal.

A well-planned layout of equipment is an important aspect of plant sanitation. There should be adequate working space for each operation, with no crowded machinery. A common error in plant expansion is to install additional machinery and equipment without a corresponding increase in floor area. Such expansion usually results in more hazardous working conditions as well as in adding to the sanitation problem.



Figure 1.—Well designed equipment for unloading salmon.

Plant Management

For a sanitation program to succeed, the plant management, of course, must support the program. In larger plants, a sanitation inspector should be appointed. In smaller ones, the owner or the superintendent of the plant should be responsible for sanitation.

The inspector should be able (1) to determine the sanitation requirements of the plant, (2) to prepare a sanitation program, (3) to check on sanitation as a routine daily operation, and (4) to evaluate the results of the program. He should make certain that the machine equipment, small equipment (such as pans and knives), floors, walls, tables, stools, and any item or area that may have become soiled are cleaned properly. He should inspect washroom and restroom facilities for cleanliness and should insist that workers wash their hands after each absence from the work area. Obnoxious personal habits of workers such as spitting on floors, smoking in work areas, and wearing soiled clothing should not be tolerated.

The sanitarian should also inspect the entire plant routinely for signs of rodents, insect infestation, and physical plant failures such as cracked paint and flaws in other surface areas. He should then see that immediate steps are taken to remedy any failure in the sanitation program.

GRADING FISH AND SHELLFISH FOR QUALITY

The usual practice when fish and shellfish are delivered to the shore plant is to inspect and grade them for quality immediately. A good starting point in determining quality, before one actually inspects the fish or shellfish, is to observe the housekeeping practiced aboard the vessel that delivers the fish. A clean-appearing, shipshape vessel usually indicates that care has been taken to insure the delivery of good-quality fish and shellfish.

As the fish or shellfish are unloaded from the delivering vessel, they are graded for quality by an experienced member of the shore-plant crew, by a fish buyer in certain fisheries, or by a professional full-time inspector.

Fish

Methods of determining the quality of fish as they are landed at the shore plant are based, for the most part, on observed characteristics. The general characteristics that the fish should exhibit are listed below:

1. The fish should have bright shiny scales and characteristic colorings and markings. (As the quality of the fish deteriorates, these colors and markings fade and become less pronounced.)
2. The eyes should be bright, transparent, and protruding. (As the quality of the fish deteriorates, the eyes become sunken and cloudy, and sometimes become covered with a pink slime.)
3. The gills should be bright red and clean appearing. (As the quality of the fish deteriorates, the gills usually fade to pink, then to gray, and finally to brown or to dark green.)
4. The fish should have a characteristic mild fresh odor and no off-odors. (As the quality of the fish deteriorates, the odor changes from the characteristic mild fresh odor to a disagreeable off-odor.)
5. The flesh of the fish should be firm and elastic. (Fish that have been poorly handled or cared for and that have been held for an extended storage period aboard the vessel exhibit various degrees of soft texture.) Fish frozen at sea and then thawed exhibit, in most instances, the same general characteristics as do fresh fish.
6. The fish should show no signs of body damage. (Fish that have not been properly handled may show body damage from rough handling, from fish pews, or from use of too coarse pieces of ice in preservation.)

In the quest for an objective test to determine the freshness of fish, workers at the Torry Research Station, Aberdeen, Scotland, have carried

out experiments on judging the freshness by the glaze in the eyes of the fish. In this method, the fish eyes are compared with a series of glass eyes filled with liquids of different cloudiness, each corresponding to the eye glaze of fish of known out-of-water history (Anonymous 1954).

Shellfish

In most operations, shellfish ^{1/} should be active and alive when delivered to the shore plant. There are a few exceptions, however, as in the case of shrimp that are iced or frozen at sea and as in the case of king crab that may be processed and the meat frozen at sea. The Manual of Recommended Practice for Sanitary Control of the Shellfish Industry (Anonymous 1946) should be referred to by those who inspect shellfish during unloading. Characteristics that the various shellfish should exhibit when delivered to the shore plant are as follows:

1. Clams should be alive. (A live clam will close its shell when disturbed.)
2. Crabs of all species should be alive and active.
3. Shrimp should be preserved in ice. They should have a mild characteristic shrimp odor. (Stocks of shrimp with strong off-odors, marked softening of body texture, or severe black-spot discoloration should be discarded.) Shrimp frozen at sea, when thawed, should exhibit the same characteristics as do fresh shrimp.
4. Lobsters should be alive and active.
5. Scallops are shucked at sea, and only the muscle meats, packaged in bags and preserved in ice, are brought to the shore plant. The fresh meats should have a mild odor. (Stocks with strong off-odors should be discarded.)
6. Oysters should be alive. (Live oysters will keep their shells closed when disturbed.) (This industry is under the sanitary supervision of the U. S. Public Health Service, and its inspection codes should be followed.)

DIVERSITY OF METHODS OF HANDLING FISH AND SHELLFISH

The fishermen of the United States take their catches from the waters of the Atlantic Ocean, Pacific Ocean, Gulf of Mexico, Bering Sea, Great Lakes, Mississippi River, and many of the smaller lakes and rivers of this country. Therefore, to describe how all species of fish are handled after being landed would be an immense undertaking. Thus, of necessity, the following discussion has been limited to the topics that are believed to exemplify best the handling of fresh fish and shellfish in the United States.

^{1/} The various species of shellfish are discussed individually in Fishery Leaflet 430, section 2.

PREPARATION OF ROUND AND DRESSED FISH--HANDLING OF FRESH-WATER FISH AS AN EXAMPLE

The commercial fresh-water fisheries are concentrated primarily in the Great Lakes, other large inland lakes, and the Mississippi River and its tributaries. The more important species in terms of value of fish landed are catfish and bullheads, carp, chubs, whitefish, yellow pike, blue pike, lake trout, lake herring, yellow perch, sheepshead, smelt, and suckers. The fish are caught principally in trap nets, seines, and gill nets. In general, as the fish are removed from the nets, they are sorted according to species into 50-pound or 100-pound wooden boxes, which are kept on the deck of the



Figure 2.--Dipping smelt from net in winter.

the fishing vessel. Usually, the fish are not iced aboard the vessel but are landed on the same day that they are caught.

Methods of Unloading Fish from Vessel to Shore Plant

The boxes of fresh-water fish are hoisted mechanically or are lifted by hand from the fishing vessel to the dock. They then are taken to the fish house on carts or hand trucks if the fish house is located near the dock or are hauled by motor truck if it is located at a distance.



Figure 3.--Removing lake herring from trap net and placing them in boxes. (Photo courtesy of Detroit News.)



Figure 4.--Unloading lake herring at the shore plant. (Photo courtesy of Bay Port Fish Company, Bay Port, Michigan.)

Handling Procedures at the Fish House

Many of the fish companies serve as combination fish producer, fish processor, wholesaler, and retailer. The handling of the fish at the shore plant therefore varies and depends upon how the fish are disposed of. In the fish house, the boxes of fish are first weighed. One convenient practice is to weigh into each box either 50 pounds or 100 pounds of fish. (The fish are less likely to undergo subsequent damage from crushing if they are held in the smaller

boxes.) Fish that are sold to local fish dealers may be iced or may leave the fish house without further handling. Fish that are sent to fish dealers in distant cities are repacked and surrounded by ice in wooden boxes and then are shipped to the market by truck or by rail. Fish that are to be processed or that are to be sold in the firm's retail store are iced in boxes and stored in a cool room until needed. Care is taken not to bruise or break the flesh by rough handling. Other fish are



Figure 5.--Fifty pounds of lake herring. These fish have been laid in a bed of ice and now are ready for top icing. (Photo courtesy of Bay Port Fish Company.)

packed surrounded by ice in 100-pound-capacity wooden boxes, are frozen, and are placed in cold storage. When fresh fish are scarce during the off season, these frozen fish are thawed, processed, and sold to the institutional trade or in the firm's retail store.

Much of the fresh-water fisheries is highly seasonal and is characterized by short periods of large catches. During these periods of gluts, a delay in icing or inadequate icing of the fish may result due to shortages in labor and in facilities for handling the fish.



Figure 6.--Stacking boxes of iced lake herring in a refrigerator car. (Photo courtesy of Bay Port Fish Company.)



Figure 7.--Scaling lake herring. (Photo courtesy of Bay Port Fish Company.)

Preparation of Fish for Use in the Fresh-Fish Trade

Most of the catch of fresh-water fish is marketed as round fish or as eviscerated fish. In general, the processing of the fish consists of scaling, washing, and either dressing or filleting the fish. The dressed fish and fillets are packed in various containers such as 30-pound fillet tins, waxed cartons, and wooden boxes. They are stored either in a cool room or in ice and usually are sold to the institutional trade or in the retail store of the firm.

Handling Procedures for Certain Species

The various species of fresh-water fish are handled in several different ways. Catfish and bullheads, for example, are eviscerated, headed, skinned, and washed before being shipped to the fresh-fish

market. Other species, such as lake trout, are not skinned. They are simply eviscerated and gilled immediately after being landed and then are carefully iced in wooden boxes before being shipped.

Some species of fresh-water fish are used largely to produce a smoked product. Typical of this type of operation is the chub fishery. The chubs are eviscerated and are packed in wooden fish boxes (50-pound or 100-pound capacity) aboard the vessel. On shore, they are washed and are prepared for smoking. The surplus chubs are placed in waxed cartons of varying capacities, are frozen, are ice glazed, and then are stored for use during the off season. Best results have been obtained by using a polyethylene bag liner inside the cartons to help preserve the ice glaze during the period of cold storage. Chubs that are to be smoked in distant cities are taken directly from the vessel, are iced in wooden boxes, and then are shipped by truck or by rail.

Certain species of fresh-water fish are used both for human food and for animal food. Typical of these species are the lake herring, which are caught in gill nets.



Figure 8.—Dressing lake herring.
(Photo courtesy of Bay Port Fish Company.)

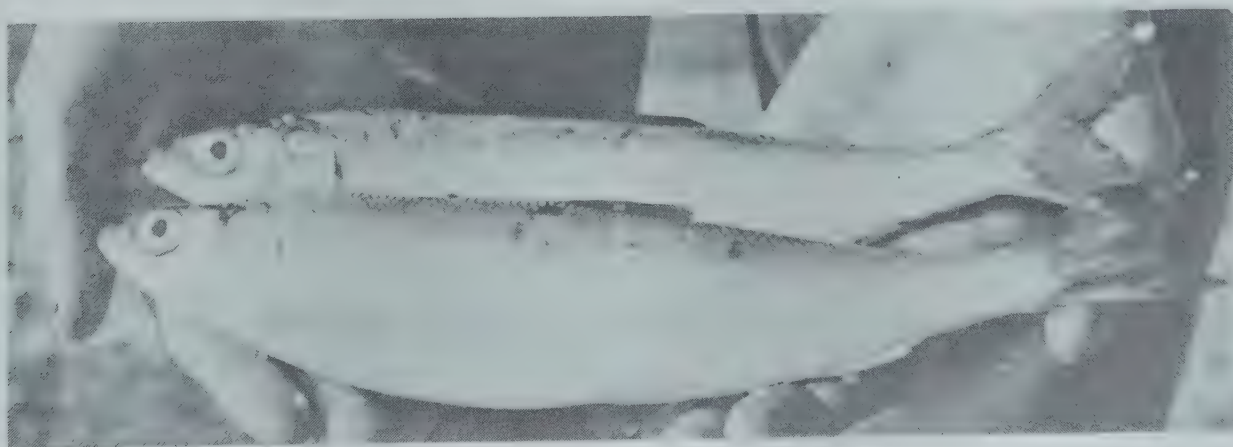


Figure 9.—Lake herring (Leucichthys artedii). (Photo courtesy of Bay Port Fish Company.)

The lake herring that are used for human food reach the processing plant usually in 100-pound wooden boxes. They are scaled and are washed. Some are processed into headed and dressed fish, and others are cut into fillets. They are sold mainly on the fresh-fish market, but some are packed in 1-pound and 5-pound waxed cartons and are frozen.

The lake herring that are used for mink food are taken primarily in Lake Superior, where they are caught in great abundance during the winter months. These fish are left in the gill nets until the vessel has docked, at which time they are picked from the nets either aboard the vessel or in a small building built alongside the dock. These fish usually are packed in wooden boxes or bushel baskets and are frozen.

PREPARATION OF FILLETS--HANDLING OF NEW ENGLAND GROUNDFISH AS AN EXAMPLE

Groundfish may be defined as those fish that normally live at the floor or the bottom of the sea and that are taken for human consumption. These fish are the demersal or bottom-dwelling species, such as codfishes and flatfishes, as contrasted to the pelagic species, such as tunas, herring, and menhaden. Although groundfish are caught off the Pacific coast, they are taken in largest quantities off the New England and the eastern Canadian coasts. The methods employed in landing these fish for shore processing are generally similar in all of the New England ports and are the ones that will be described here.

Methods of Unloading Fish from Vessel to Processing Plant

The larger species of fish such as cod, haddock, pollock, and the flatfishes are transferred from the storage pens of the vessel into canvas unloading baskets by one- or two-tined pews. The worker, in pewing the fish, should pierce them only in the region of the head to avoid wounds in the edible flesh. The unloading baskets, which are constructed of a canvas liner within a steel framework, have a capacity of 90 to 100 pounds of fish. The baskets, when filled, are hoisted onto the dock by means of a winch and then are emptied into a tared 500-pound-capacity wooden box that has been placed on platform scales. In some ports, weighing boxes are not used; instead, the fish are weighed in the unloading baskets or on pan scales. The fish, after being weighed, usually are pewed into large two-wheeled wooden carts, of about 1,000- to 2,000-pounds capacity, which then are pushed into the processing plants. In some instances, the loaded weighing boxes are moved into the plant on a tractor-drawn trailer.

Smaller species of fish such as ocean perch, whiting, and flatfish are usually shovelled out of the pens of the vessel into the unloading baskets. The workers, in shovelling the fish and even in pewing, inadvertently include considerable amounts of ice with the fish. In some ports where the fish are weighed and sold as they are unloaded, a five-percent or larger discount in weight is allowed to take care of the extra ice. The more common practice, however, is to empty the unloading baskets directly

into a de-icer on the dock. This de-icer is a cylinder that is 2 feet in diameter and 12 feet in length and that is made of expanded metal or screening of $1\frac{1}{4}$ -inch mesh. The cylinder rotates about a central spray pipe and is inclined downwards at a small angle. As the fish and ice tumble toward the lower end of the cylinder, the ice is washed through the sides of the machine. The de-iced fish then fall onto a rubber belt and are conveyed to the weighing boxes. The fish, after being weighed, are either conveyed by belt directly into the shore processing plant or are loaded into wooden boxes, with ice for transportation to distant markets.



Figure 10.—Unloading fish from a hold of the ship by the use of a canvas basket and a winch. Note the basket in the air being swung out of the hold. (Boston, Massachusetts)



Figure 11.--Dumping fish from a canvas unloading basket into a tared weighing box. A large two-wheeled cart partly filled with fish is shown in the lower right-hand corner.



Figure 12.—Loaded weighing boxes on a tractor-drawn trailer on the way to a processing plant.

Plant Storage Prior to Processing

At times, the shore processor will receive a glut of fish, necessitating their storage prior to processing. The storage time involved may be from a few hours up to an overnight period. Storage bins, chill rooms maintained at 35° F., or a designated floor area within the shore plant are used to store these fish. If the processor receives the fish in boxes, the usual practice is to add crushed ice and to store them in a chill room or other designated area of the plant. In those plants in which the fish are received by conveyor belt or by two-wheeled carts, the fish are layered with ice either in storage bins or on a section of the floor.

Recommendations for Controlling Quality before Processing

Because of the rapid deterioration of fish flesh and because only fish of the highest quality bring premium prices, it is vital to the shore processor to take steps to maintain fish at the highest quality possible. The processor should acquaint himself thoroughly with the bacterial and enzymatic deterioration occurring in fish flesh and with the methods of retarding such actions (section 1 of this leaflet). The processor should also acquaint himself with the quality control recommendations for handling fish at sea (section 2) and demand that those vessels supplying him with fish comply with these recommendations.

Preparation of Fillets

A fillet is a piece of flesh, substantially boneless, cut away from either side of the fish along the backbone from behind the pectoral fin down to the tail section of the fish. If that portion of flesh that lines the visceral cavity remains with the fillet, the fillet is called a full-nape fillet. Most high-quality fillets do not contain the nape.

The first commercial preparation and shipment of fillets was made on December 21, 1921, and is credited to Mr. Dana Ward. Fresh haddock fillets individually wrapped in vegetable parchment were packed in 20-pound-capacity hinged wooden boxes.

Although the fillets kept well during the winter, they tended to spoil rapidly during the summer because of the lack of refrigeration. This problem was solved by packing them in tin containers, which in turn were packed with crushed ice in wooden shipping boxes. Since the inception of the first commercially packed fillets, the Massachusetts production of fillets has grown from an insignificant quantity in 1921 to almost 34 million pounds in 1952.

Fresh fillets are generally marketed in one of the following ways: skin on, in which the skin of the boneless fish flesh is left on, as in ocean perch and whiting; skinless, in which the skin is removed as in cod, haddock, cusk, and the flatfishes; and butterfly fillets, in which the

fillets are left adhering together by the uncut skin of the belly, as in whiting.

Filleting by hand.--Before the fish are filleted, they are washed with chlorinated water, either in wash tanks or under sprays, in order to remove the slime, blood, and ice. The chlorinated water also has the effect of greatly reducing the number of surface bacteria. If the fish are to be sold as skin-on fillets, the scales are removed with a small, powered hand scaler. The fish, after being scaled, are rinsed under running water. All fish, whether scaled or not, are carried by a rubber conveyor belt to a large hopper that feeds the filleting tables. When the cutters need fish, a conveyor system from the hopper to the filleting table is started, and each worker removes a supply of 50 to 100 pounds of fish from the moving belt.



Figure 13.--Filleting ocean perch by hand.

The hand-filleting cuts for all fish are quite similar. The filleter, using a very sharp and flexible knife, makes his first cut behind the

pectoral fin across the body and down to the backbone. When the backbone is reached, the knife is held flat, and a second cut is made along the backbone parallel to the dorsal fins, from the first cut to the tail. The cut is then opened, by the filleter's free hand, at the junction of the first two cuts. The filleter next cuts along the backbone around the visceral cavity down to the vent, and then down to the tail in one motion (see illustrations of filleting in Fishery Leaflet 431, section 3). The fish is turned over, and the operation is repeated. The fillets are finally placed on a moving belt that conveys them to a brining tank. The waste portions are thrown onto another conveyor belt emptying into a central waste-storage hopper.

If the fillet is to be skinned, it is placed on the table skin side down. A cut is made across the fillet down to, but not through, the skin at about 1/2 inch from the tail end of the fillet. The filleter then grasps the tail end of the fillet with his free hand and pulls while cutting with the knife just above and horizontally to the skin. The skin and its adhering scales are thrown onto the waste conveyor, and the skinless fillet is placed on a rubber conveyor leading to the brining tank.

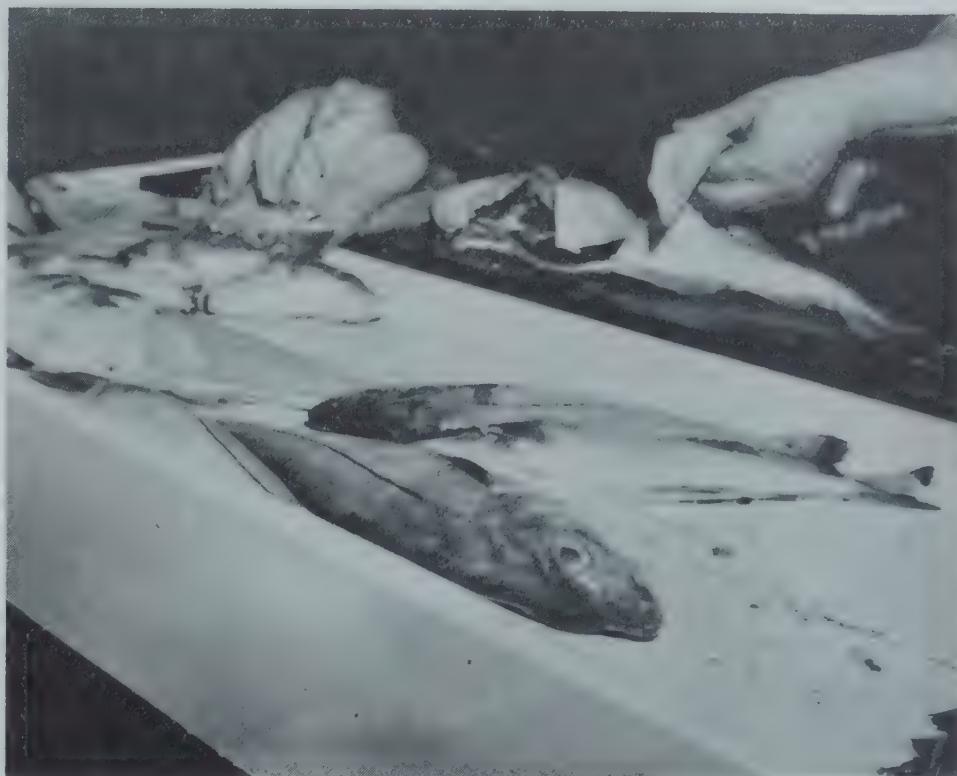


Figure 14.--Hand filleting haddock. The filleter is making the last cut, from the vent to the tail along the backbone.

Brining has a twofold purpose: (1) it helps the fillet to retain water, by lowering the amount of drip, and (2) it enhances the appearance of the flesh. Some processors chlorinate the brine solution in order to reduce the number of bacteria on the surface of the fillets.

The period of time the fillets remain in the brining tank depends upon the concentration of the brine. For a 10- to 15-percent brine, a dip of 20 seconds is used, and for a 3-percent brine, a dip of up to 2 minutes is used (Holston and Pottinger 1955). The period of time that the fillets are in the brine solution is regulated by the length of the tank, which usually is about 4 feet, and by the speed of the conveyor belt that moves the fillets through the tank. The conveyor belt usually is made of stainless steel or of some other metal that is resistant to the corrosive

action of the brine. In some plants, the brine solution is continuously filtered to remove broken pieces of flesh.

The fillets, upon emerging from the brining tanks, are drained and are conveyed to the packing tables and, before being packed, are inspected for bruises, fins, and bones, which, if found, are removed. Iced fillets usually are wrapped individually in vegetable parchment paper or in cellophane and then are packed into tinned slip-covered metal fillet cans of 20-pound capacity. Five-, ten-, and twenty-pound waxed chipboard or fiberboard cartons with telescoping covers also are used. The fillets are sometimes quickly cooled to about 30° F. by placing the containers in an air blast at 0° F. To maintain the fillets at 32° F. during shipment to market, the processors pack the containers in crushed ice in large wooden boxes. Fiberboard cartons are used at times instead of the wooden boxes when prechilled fillets are rushed to market by air or, over short distances, by truck.

Ocean-perch fillets are candled before they are brine dipped and packed. The candling table consists of a sheet of Plexiglas illuminated from below by a 100-watt bulb. Here the individual fillets are inspected for bruises, fins, and parasitic contamination. If any of these undesirable features are detected, they are trimmed out, if possible, or else the fillet is rejected.

Filleting by machine.--Within the past few years, there have been several new labor-saving devices made available to filleting plants. These devices consist of heading, scaling, filleting, and skinning machines.

Fish received at the filleting plant are conveyed into hopper bins, of 400-pound capacity, which are mounted on scales. Weighings are made continuously. From the hoppers, the fish are carried by a flight conveyor under sprays of potable water and then to a belt system leading to a battery of heading machines. The fish are placed by hand 1 foot apart, with the gills facing an angle-iron stop, on metal cleats attached to a chain-type conveyor that feeds into the heading machine. The fish are forced against a rotary knife, which cuts off the heads. The capacity of the heading machine is 100 fish per minute. After the heads are removed, the body is conveyed to an automatic scaler, and the heads are conveyed to a waste bin on the outside of the plant.

The scaler may consist of a revolving expanded-metal drum such as is used on ocean perch and on whiting, or it may consist of a unit in which the fish are drawn head first against a high-speed coarse-metal cylinder. A scaler of the first type is capable of processing 15,000 pounds of ocean perch per hour, and one of the second type is capable of processing 4,000 pounds of scrod haddock per hour. Both types of scalers employ liberal amounts of water to wash away the loosened scales.

From the scaler, the fish are conveyed to a filleting machine that is provided with high-speed rotary knives and parallel ribbing knives.

Fish entering this machine are grasped by the tail mechanically and are guided past the two kinds of knives. As the fish travel past these knives, the fillets are removed. One machine is reported to be capable of processing 75 fish per minute. The filleting machines can be so adjusted as to cut the fillets with the nape on or with it off, the latter being the general practice. The frame or skeleton is conveyed to a hopper for the storage of waste, and the fillets are sent to a skinning machine.

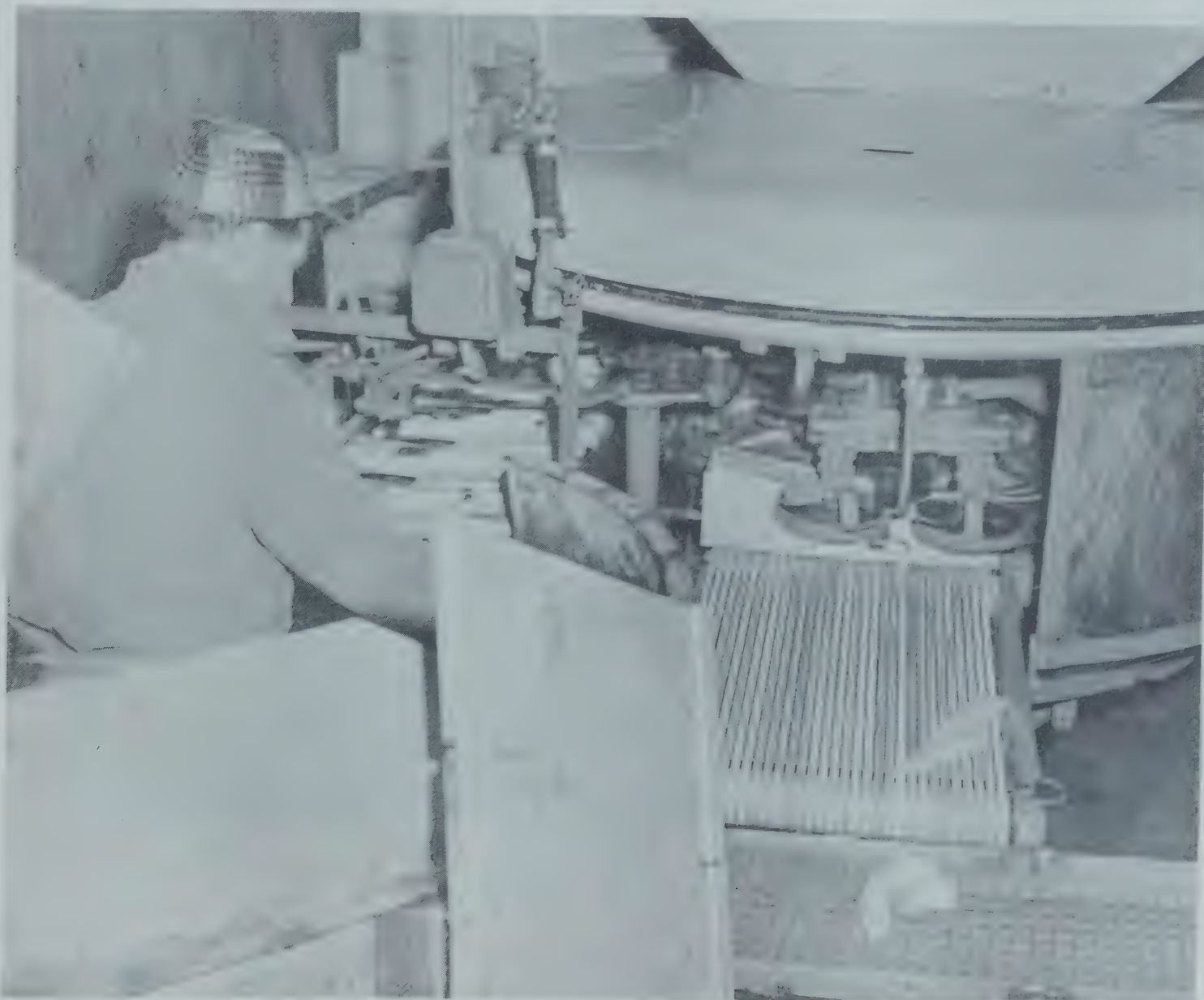


Figure 15.--Filleting machine cutting haddock. The feed is on the left side of the machine, and the fillets, with skins on, come out on the belt on the right side. (Photo courtesy of Shamrock Fisheries.)

Species such as cod, haddock, and pollock are usually sold as skinless fillets. On one type of skinning machine, the fillets are placed skin side down on a rubber belt. Above the belt is a high-speed band knife so installed that the distance between the belt and the knife can be adjusted easily. A second belt is placed above the knife and the lower belt in such a manner as to apply an even, firm pressure on the fillet.

As the fillet moves between the belts, the knife slices off the skin. This machine also can be used to split thick fillets that would come from large cod, haddock, or pollock. The capacity of such a machine is reported to be between 3,000 and 4,000 pounds of fillets per hour.

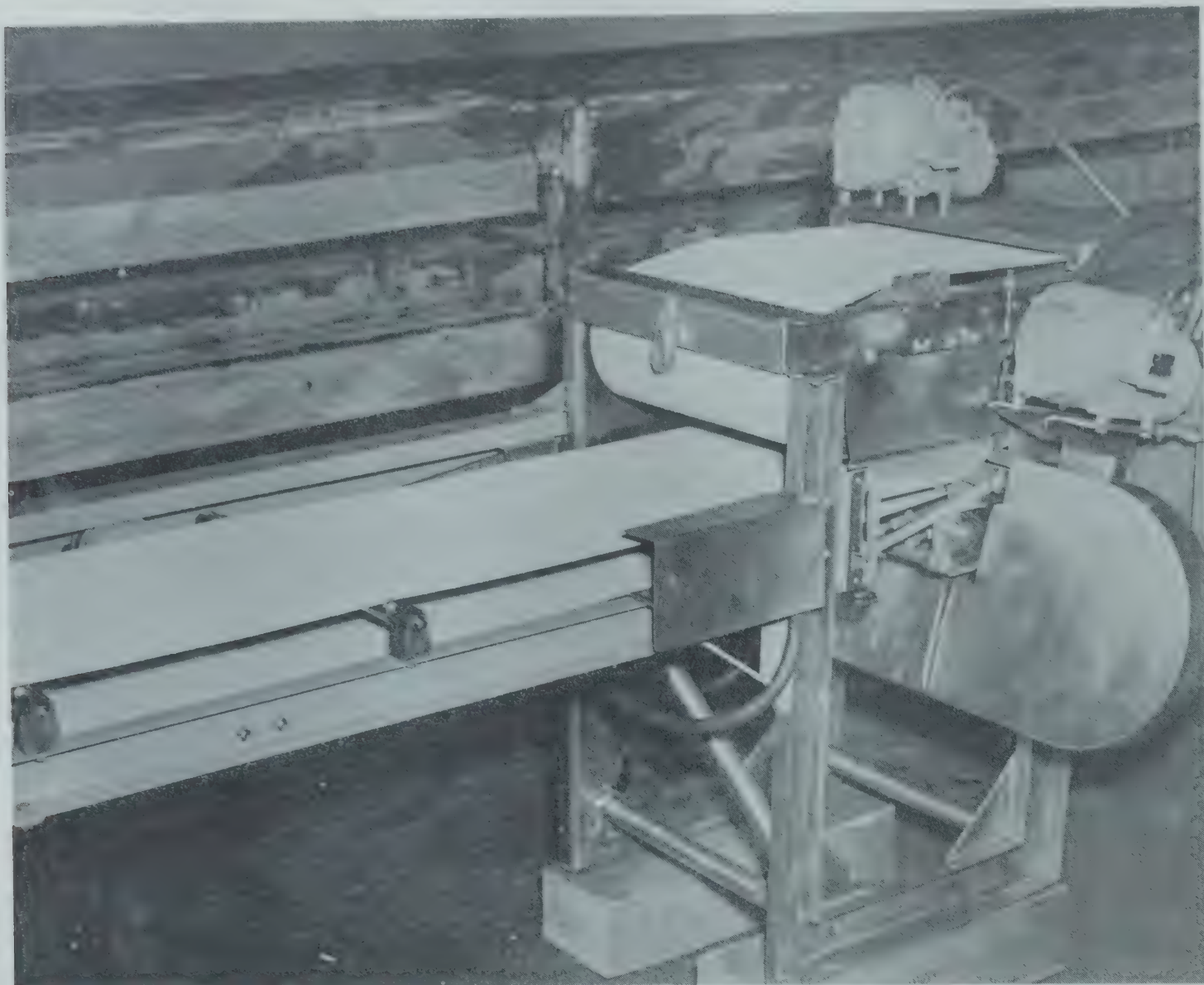


Figure 16.--Typical skinning machine. (Photo courtesy of Jensen Equipment Company.)

The fillets are inspected and brine dipped as was previously described. They are drained on a mesh belt and are dropped into cartons or corrosion-resistant pans set on scales to obtain an approximate weight. The containers then are sent to a packing table, where their weight is adjusted. The containers used are the same as was described in the previous section on hand cutting of fillets.

PREPARATION OF FROZEN STEAKS---HANDLING OF HALIBUT, SALMON, AND SABLEFISH AS EXAMPLES

Why Certain Species of Fish are Frozen for Steaking or Filleting

Most species of fish are landed in the unfrozen state from the fishing

vessel, are processed into fillets or other desired cuts, are packaged, and then are frozen. Halibut, salmon, and sablefish, which are caught mainly in the Pacific Northwest and in Alaska, are trimmed and washed thoroughly after being landed, and then are frozen and are stored as whole glazed fish. These whole fish are withdrawn at intervals as orders are received. Steaks or fillets are cut from either the hard-frozen fish or the partially thawed fish, and the cut product is packaged, refrozen if necessary, and returned to cold storage.

There are two considerations that have led to this practice:

First, halibut and salmon are caught during a relatively short season, usually in areas remote from locations that have complete processing plants. In Alaska, for example, it is easier to ship whole frozen fish to centrally located plants for cutting and packaging than it is to carry out these latter operations at widely scattered locations.

Second, halibut and salmon, like other kinds of fish, have a much longer cold-storage life when stored as glazed whole fish than as steaks. Steaks cut from frozen fish cannot be packaged without leaving considerable air space inside of the package. This method of packaging thus does not provide adequate protection for prolonged storage. The better practice therefore is to store the fish for as large a part of the total storage period as is possible in the form of glazed whole fish.

A few processors have developed equipment for cutting unfrozen or partially thawed fish into steaks. When such steaks are packaged and are frozen under pressure, the pieces fill the space inside the package. Such fish then have increased storage life, and it is not so important to hold them in the whole dressed and glazed state initially.

Steaking and Packaging Frozen Fish

Halibut steaking.--A processing line similar to the one shown in figures 17 and 18 is usually employed in the steaking of frozen halibut.

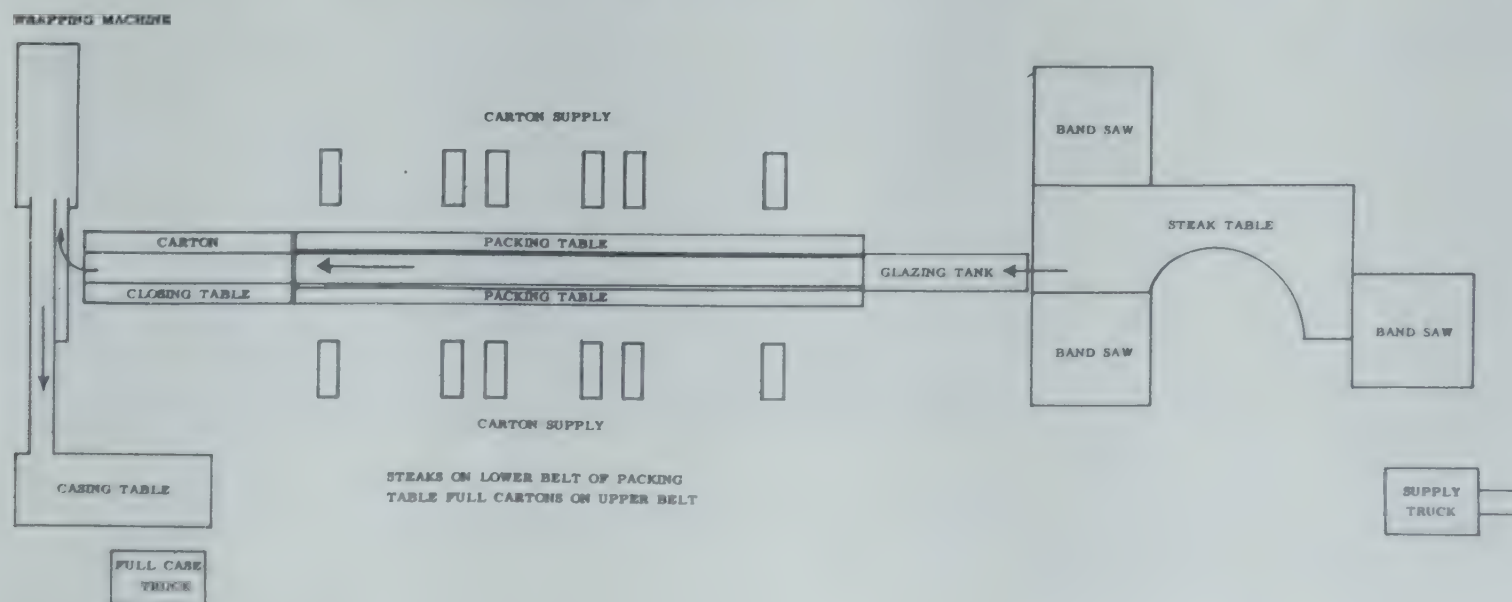


Figure 17.—Line for steaking and packaging frozen halibut.



Figure 18.--Packing line for frozen halibut steaks. The man in the foreground is the first sawyer. (Photo courtesy of Seattle Seafoods, Inc.)

These facilities may be more highly mechanized or less highly mechanized than is the one shown, depending upon the cost of equipment, the cost of labor, the desired throughput, and the maximum unit packaging cost that can be borne by the product.

The usual starting material in cutting steaks is frozen halibut, dressed head-off and weighing from 10 to 60 pounds. Immediately after the halibut are removed from frozen storage, the dorsal and the ventral fins are shaved away with a

large sharp knife. The halibut then are hauled to the first bandsaw in a buggy or a cart. A man known as the first sawyer carries the halibut, one at a time, to the first saw and begins the steaking operation. With his initial cut, he removes 2 or 3 inches of gristle at the nape of the neck. With his second cut he removes the belly and the nape as one unit. With his third cut, he separates this unit into two pieces. He then throws the belly piece into the scrap box and proceeds to cut $\frac{3}{4}$ - or $\frac{7}{8}$ -inch-thick steaks from the nape piece and from the loin piece. The steaks get smaller in diameter as the tail is approached. He therefore discards the tail piece when the steaks are no longer large enough for a single small serving.

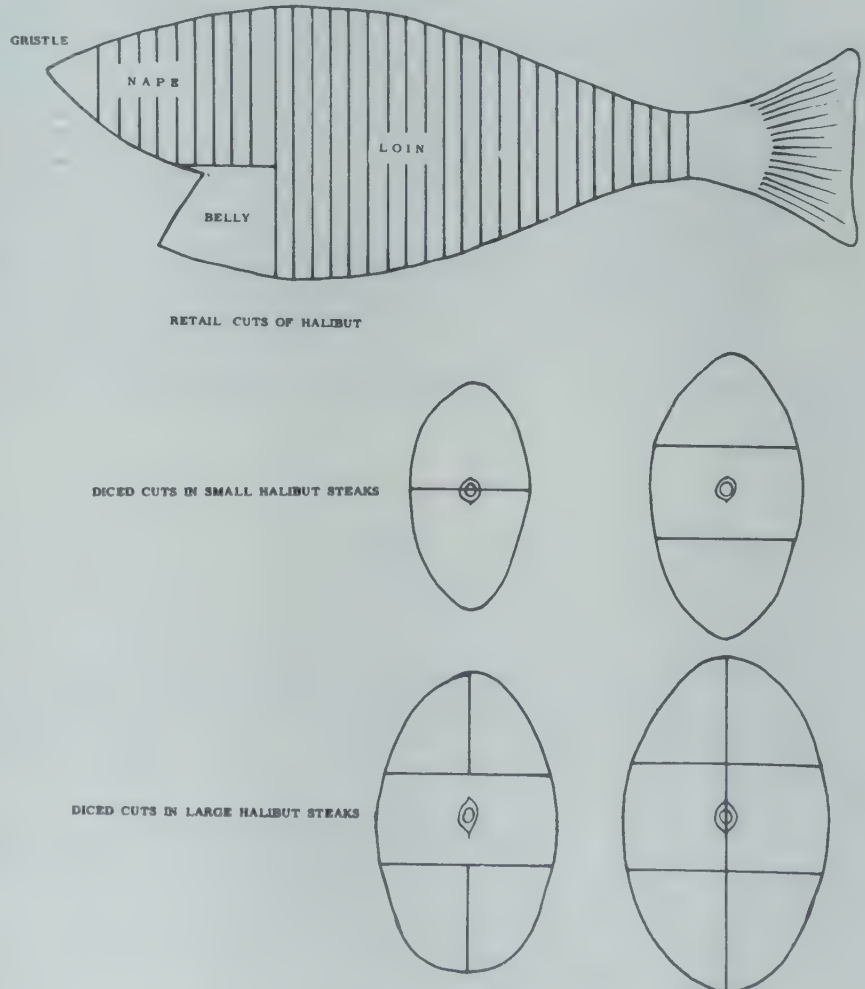


Figure 19.--Cuts of halibut steaks.

If there are three sawyers working together, a second sawyer receives the belly piece, trims away the fins and the thin belly wall that is less than 1 inch thick, and cuts steaks from the remainder. Steaks from the first and second sawyer are passed along to a third sawyer, who dices or cuts them into serving-size pieces suitable for packaging. If there are only two sawyers, the second sawyer trims and steaks the belly piece and dices all of the steaks. Sometimes a number of belly pieces are accumulated, trimmed, and steaked by the first sawyer. Trimmings and sawdust from the steaking operation are used



Figure 20.--Steaking a frozen halibut loin.
(Photo courtesy of Seattle Seafoods, Inc.)

for pet food or for mink food. The yield of salable halibut steaks from dressed frozen halibut is about 70 percent of the weight of the dressed halibut.



Figure 21.--Dicing frozen halibut steaks.
(Photo courtesy of Seattle Seafoods, Inc.)

Halibut packaging.--

After the steaks have been cut into serving-size pieces, they are dropped into a glazing tank containing cold water, from which they are lifted by an inclined mesh-belt and delivered to the packing table. Some glazing operations employ a spray of water above and below the mesh-belt to



Figure 22.—Weighing frozen halibut steaks into a carton. (Photo courtesy of Seattle Seafoods, Inc.)

obtain a thicker glaze.

Waxed cartons for packaging the steaks come in flat cut blanks and are formed by hand, by hand-operated machine, or by automatic machine. They then are either carried in large boxes to the packers or are conveyed along the packing table on a supply belt. The packer takes cartons from the supply belt, places them on the scale pan, fills them with pieces of halibut steaks to a weight of 1 pound, and then places them on a conveyor belt running to the lid-closing table, where they are closed by hand.

(These cartons of necessity must be large enough to hold odd-shaped frozen pieces without crowding, consequently they contain considerable air space.) The closed cartons then are fed either automatically or by hand to the machine that overwraps



Figure 23.—Closing cartons filled with frozen halibut steaks and feeding the closed cartons to a wrapping machine. (Photo courtesy of Seattle Seafoods, Inc.)

them with printed waxed paper and heat seals the paper. Wrapped cartons are packed in fiberboard shipping cases and are returned to storage at 0° F. or lower. Institutional size packs of steaks are packed in fiberboard boxes that have a capacity of 15 pounds. These boxes or cases are lined with heavy waxed paper, and a sheet of this paper is placed on top of each layer of steaks. When the box is full, the lining paper is folded over the top layer of steaks, and the box is glued shut. If the box is of two-piece construction, it is strapped shut.



Figure 24.—Packing wrapped cartons of frozen halibut steaks into shipping cases. (Photo courtesy of Seattle Seafoods, Inc.)

Salmon and sablefish steaking.--Salmon and sablefish are steaked with the same type of equipment that is used for steaking halibut and are handled in much the same manner except that only two saws are required. In steaking salmon, the first sawyer trims away the fins, saws off the head behind the gills, and saws off the collar or nape piece, which contains the tips. (Frequently, these tips are saved and smoked for sale as kippered salmon tips.) The second sawyer simply cuts steaks right down to the tail piece. Tail steaks too small for a single small serving are thrown aside for use in animal food. For institutional packs, however, the tail piece is filleted and is packed with the steaks. Salmon steaks ordinarily are not large enough to require dicing or cutting into individual portions.

Salmon and sablefish packaging.--Salmon and sablefish are packed in retail-size cartons and in institutional-size cartons in the same way as are halibut steaks and then are returned to 0° F. storage. The yield of salable steaks ordinarily is about 70 percent of the weight of the dressed heads-on frozen salmon, but it may exceed this value.

Steaking, Filleting, and Packaging Partially Thawed Fish

Halibut steaking and packaging.--When the supply of freshly frozen halibut steaks packed in May and June has been sold, it is the practice in some plants to pack new supplies of steaks by partially thawing frozen dressed halibut that have been held in storage at 0° F. or colder. A

processing line similar to the one shown in figure 25 is usually employed for steaking partially thawed halibut. Medium halibut from 10 to 60 pounds are best suited for steaking. The frozen halibut are brought out of storage; the dorsal and ventral fins are shaved off with a sharp knife; and the halibut are put to thaw in air, on the floor of the fish house, or in circulating water. Thawing time will depend on the temperature of the fish, the size of the fish, the temperature of the thawing medium, and the type of thawing medium used (air or water). The temperature of thawing water should not exceed 60° F. (Magnusson and Hartshorne 1952).

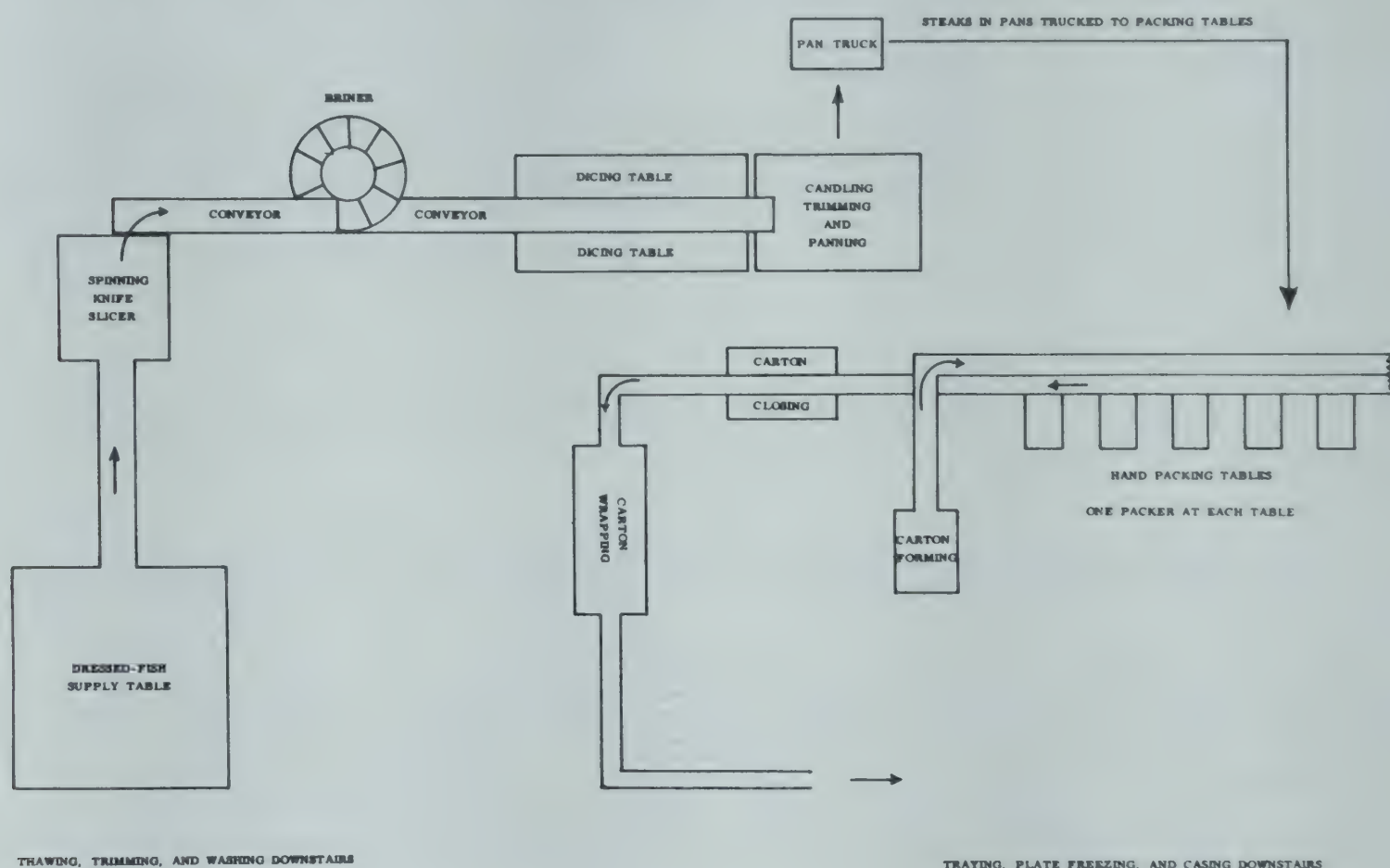


Figure 25.--Line for steaking and packaging fresh or partially thawed halibut.

Partially thawed, or slacked, halibut are more desirable for steaking than are completely thawed halibut. Furthermore, one fourth to one fifth less thawing time is required to obtain a slacked halibut, which still retains a large quantity of ice crystals, than is required to obtain a fully thawed halibut. The time required for thawing halibut to the slacked stage can best be determined by practice under actual conditions.

The first steps in preparing slacked halibut for steaking are washing and trimming. The halibut is scraped inside and then is scrubbed inside and out with water. The thin belly flaps are cut away, and the nape is cut off back to where a good slice can be obtained. The washed and trimmed halibut then are transported to the steaking plant or room.



Figure 26.--Slicing partially thawed halibut. (Photo courtesy of Pacific Fisherman.)

Slices $7/8$ -inch thick are cut one at a time on a specially constructed slicing machine (Beard 1953). The tail portion of the halibut is collected along with the nape pieces, from the smaller halibut, filleted, and packed in fillet cartons for freezing.

As the steaks leave the slicing machine, they fall on a conveyor and are washed under a heavy spray of water. Continuing on the conveyor, they are allowed to drain before they fall from the end of the conveyor into a stainless-

steel rotary briner. Here they are brined, like fillets, as they travel around a complete circle. After the steaks leave the briner, they are conveyed to the dicing table, where they are cut into pieces for packing into cartons of 1-pound capacity. Only steaks from large halibut require extensive cutting to obtain pieces of proper size.



Figure 27.--Stainless-steel briner for halibut steaks. (Photo courtesy of New England Fish Company.)



Figure 28.--Trimming and dicing halibut steaks to size. (Photo courtesy of New England Fish Company.)

The cut steaks then are conveyed to the inspection table, where each steak is candled over a frosted glass plate illuminated from below by



Figure 29.—Trimming, candling, and grading halibut steaks at inspection table. (Photo courtesy of New England Fish Company.)

and places it on a conveyor. This conveyor carries the filled cartons to a machine that closes the lid. After the cartons have been closed, they travel by conveyor to the wrapping machine, where a printed waxed-paper overwrap is applied. The wrapped cartons are placed on trays, plate frozen under pressure, packed in shipping cases, and stored at 0° F. or lower until shipped to market.

Freezing under pressure causes the tightly packed halibut steaks to fill the voids in the carton, thus eliminating air pockets. The resulting product is a completely filled carton having flat surfaces.

strong lights, which help to disclose any imperfections or parasites present in the flesh. The imperfections are trimmed away with a pair of shears, and the inspected steaks are put into pans and are trucked to the packing tables.

Waxed cartons into which the steaks are packed come in flat ready-cut pieces in bundles. These flat-cut pieces are formed into cartons automatically by machine and then are conveyed by belt along the line of fillet packers. Each packer stands in front of her own table, selects a carton from the belt, places it on a scale pan, fills it with pieces of steak that fit into the space in the carton, weighs it to 1 pound net,

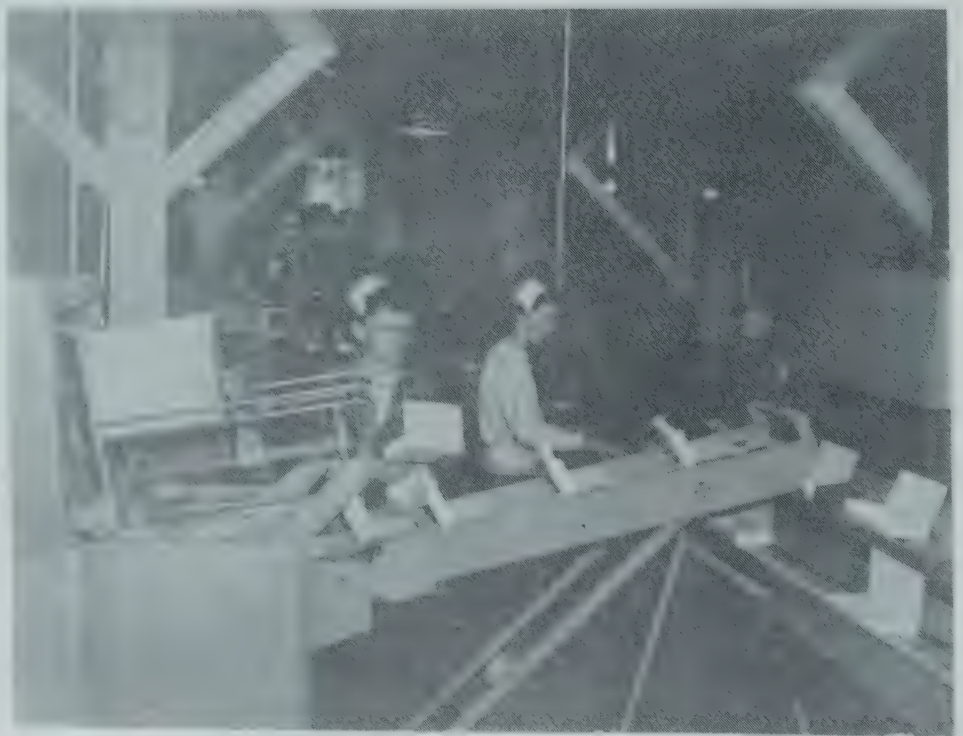


Figure 30.—Machine for making cartons. (Photo courtesy of New England Fish Co.)



Figure 31.--Packing and weighing halibut steaks into 1-pound cartons. (Photo courtesy of New England Fish Company.)



Figure 32.--Placing wrapped cartons on trays. (Photo courtesy of New England Fish Co.)



Figure 33.--Loading trays of cartons into a plate freezer. (Photo courtesy of New England Fish Company.)



Figure 34.--Packing cartons of frozen halibut steaks into a shipping case. (Photo courtesy of New England Fish Company.)

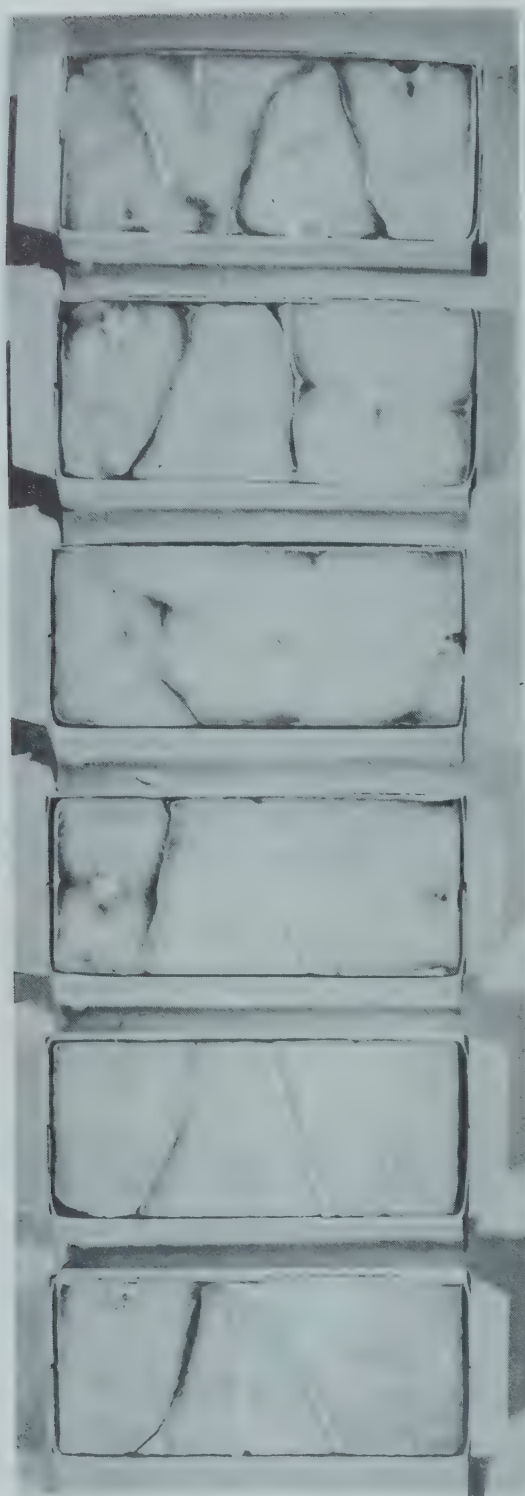


Figure 35.—One-pound packages of halibut steaks. (Photo courtesy of Pacific Fisherman.)

Halibut filleting and packaging.—As was mentioned earlier, the nape and tail pieces from the steaking operation are filleted by hand, cut into slices of suitable size, washed, brined, inspected, and packed into fillet cartons. Other types of waxed cartons similar to those in which partially thawed halibut steaks are packed may be used for halibut fillets. The packer, before filling the collapsed snap-open type of waxed carton, lines a metal mold or box with a sheet of transparent packaging film, packs the fillets into the mold, and folds the film to cover the fillets. The packer then snaps the carton open, covers the full mold with the carton, turns over the carton and mold together, withdraws the mold, and snaps shut the carton lid. The filled carton is then wrapped by machine, frozen, cased, and stored at 0° F. or lower, in much the same manner as are the halibut steaks. In this respect, halibut fillets are a by-product of the halibut-steak operation.



Figure 36.—Packaged fillets in carton after metal mold has been withdrawn. (Photo courtesy of Booth Fisheries Corporation.)

Salmon and sablefish steaking and packaging.—Steaks are cut by machine from partially thawed, dressed, washed, and trimmed salmon or sablefish. (This machine is the same one that is used to prepare halibut steaks.) The tail piece is discarded when the steaks are no longer large enough to provide a small individual serving. Very few of these steaks are so large as to require dicing or cutting in half for packing. Salmon and sablefish steaks, unlike halibut steaks, are not brined, but they are packed in cartons in the same manner as are the halibut steaks.

Salmon and sablefish filleting and packaging.—Fillets are cut by hand with a fillet knife from partially thawed, dressed, and washed salmon or sablefish. The fillets then are skinned, are cut crosswise into pieces as wide as the width of a fillet carton, and are packed, 1 pound net, into the cartons. The pieces are packed in such a manner that the thick part of one fillet overlaps the thin part of the adjacent fillet.

HANDLING OF FISH FROZEN AT SEA—PROCESSING OF TUNA AT THE CANNERY AS AN EXAMPLE

Some species of fish are frozen at sea and, after being landed, are thawed and then are processed. The most important fishery operating in this fashion is the one in which tuna are frozen in brine aboard the fishing vessel and are landed either frozen or partially thawed. After the thawing has been finished at the shore plant, the tuna are butchered, are precooked, and then are canned. A small part of the salmon catch is also frozen at sea and handled in much the same manner as are tuna except for the precook. Because the methods employed by the tuna industry are quite typical for this kind of operation, they will be described in detail.

Arrangement of Tuna Plant

Most tuna plants are located adjacent to a dock suitable for unloading fish from a vessel and are provided with rail facilities for the delivery and shipment of cans and other materials (sometimes including frozen tuna as well as the final canned product). The cannery usually faces the dock with the rail line at the rear. Ordinarily, a doorway opens from the dock side of the plant into a room where the tuna are thawed and butchered. If thawing tanks are employed, these may be in the butchering room or in an adjoining one. If there is a cold storage, it is generally adjacent to and entered from this room. The fish are usually delivered to an open space near the door and, if frozen, are merely laid on the floor for defrosting with or without sprays. The butchering table, sometimes permanently installed but in other cases equipped with casters for moving about, is usually nearby.

The butchered tuna are placed in baskets on racks, which are wheeled into the precookers. The tuna, after being precooked, are cooled, are cleaned, are packed in cans, and then are retorted. Figure 37 shows a typical layout of a tuna plant up to the point where the fish are precooked.

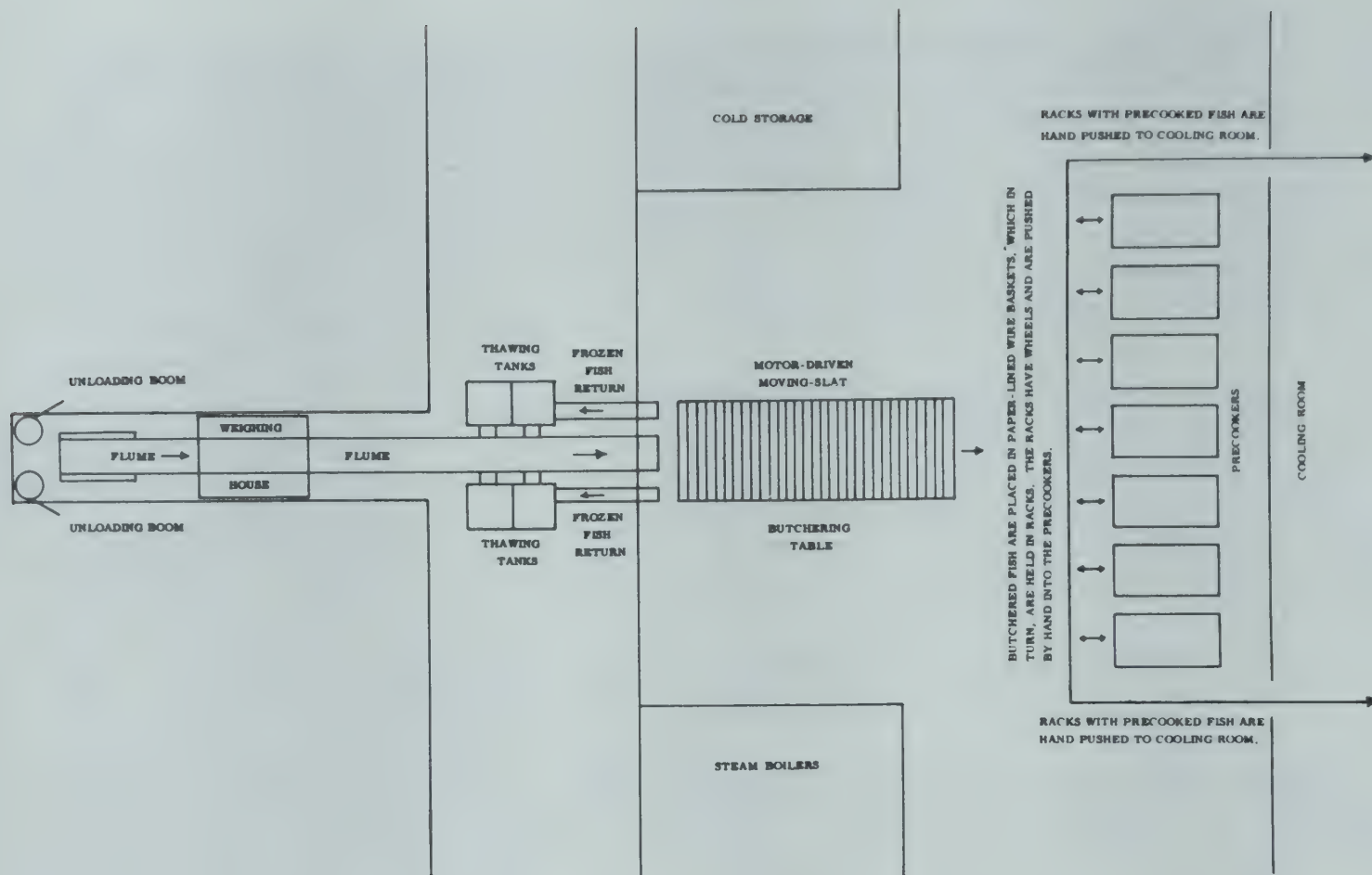


Figure 37.--A typical layout of a tuna plant.

Conveyor Systems for Carrying Tuna to the Plant

The larger canneries that are located adjacent to wharves and that have no intervening roadway or other obstruction ordinarily employ the following system. A large tub is lowered through the hatch of the fishing vessel into the hold and is filled, by hand, with tuna. The tub then is lifted out of the hold by a boom hoist and is swung over an apron, where it is dumped automatically with a catch chain. In some installations, two hatches of a single vessel can be unloaded simultaneously in this way.

The tuna fall from the dumping apron into a flume containing running sea water, which sluices them onto a slat-type conveyor-belt elevator which, in turn, lifts them to a scale house, where they are weighed, usually in the presence of representatives of both the fishing vessel and the cannery. The weighing is done in batches, with a scale hopper of about 700-pound capacity ordinarily being employed. The tuna then are sluiced through flumes to the cannery. This method is highly efficient and involves a minimum of handling. In California, it is used by the large plants in San Diego and by one on Terminal Island. Such a system can handle about 15 tons of tuna per hour.

Most of the plants on Terminal Island are located across a roadway

from the unloading docks, making the use of continuous sluiceways for conveying the fish to the plants inconvenient. A majority of these plants make use of three-wheel metal carts holding 1,000 to 1,400 pounds of tuna. These carts are lowered into the hold of the vessel, are filled with tuna, and then are lifted onto the dock by boom or, in some cases, by overhead trolley with chain lift. Otherwise, a large bucket, usually with a hinged bottom, is loaded with tuna in the hold and is dumped into the cart on the dock. The cart is wheeled over a floor-level weighing scale and then is wheeled into the cannery. This method, although requiring more labor than does the sluicing method, is reasonably efficient.

Some tuna are brought to the cannery by other means of transportation than by fishing vessel. In a few instances, the fishing vessel discharges tuna at some remote port, and the iced tuna are hauled to the cannery in large truck-trailers. The trucks then are unloaded, usually into the carts, which are wheeled into the cannery. Often, Japanese tuna are unloaded at points such as Portland or Seattle, where they are placed in cold storage. The tuna, when needed at a cannery, are packed into a truck or freight car for shipment. At the destination, they are unloaded from the freight car or truck into hand-pushed carts and are wheeled into the thawing or butchering room. The extensive handling and rehandling of such frozen tuna may result in quite serious bruising, abrasion of the skin, or other damage. Frequently, the workers, in unloading a car or truck of such fish, handle them with hooks. Although an effort usually is made to handle the tuna by the head or by the tail, occasionally they are hooked through the body, and if they are partially thawed, considerable damage may result. When the tuna are handled as many as four or five times in this way, as sometimes happens, an appreciable portion of them may show the effect of such rough treatment.

Methods of Thawing Frozen Tuna

Tuna frozen aboard clipper ships generally are thawed or are partially thawed before they are unloaded at the cannery. It is customary to turn off the refrigeration a day or two before the vessel docks. In some cases, sea water is circulated through the coils in the wells containing the frozen tuna, in order to hasten the thawing. Thawing or partial thawing of tuna aboard the vessel facilitates unloading the tuna without the danger of breaking them or otherwise damaging them when they are removed from the wells. It also reduces the thawing time required at the cannery. Frozen tuna are more easily damaged than are thawed ones because of the greater tendency for them to stick to the coils in the wells or to each other; thus, in being handled during unloading, the tuna may be damaged when they are pulled apart or pulled from the coils. It is generally inadvisable to thaw the tuna completely aboard the vessel, however, because this thawing would entail too much danger of spoilage should there be a delay between the time that they are unloaded and the time that they are canned.

Tuna unloaded by sluicing generally go directly to the butchering area. It is common to have an arrangement whereby the insufficiently thawed tuna can be diverted by opening a gate so that they are sluiced into a thawing tank. After the tuna have been thawed, they are released back into a sluiceway that carries them again into the butchering room.

The thawing of tuna in tanks is generally done only in the larger plants. More frequently, the tuna are placed in a single layer on the floor and are allowed to thaw either without other aid or, as is more usual, are sprayed with water from an overhead pipe-spray system. In a few plants, they are placed in piles and are thawed by being sprayed at intervals with water from a hose. Even some of the larger plants use spray thawing rather than tank thawing.

Because tuna, when they reach the plant, are in such a variety of stages of thawing--from hard frozen to completely thawed--the thawing time at the plant varies over a wide range. Very frequently, even though the tuna were originally frozen aboard the vessel, they are sufficiently thawed by the time they reach the butchering table that they can be butchered forthwith, for the relatively short wait from the time they reach the butchering room until actual butchering starts is sufficient to complete the thawing.

For hard-frozen tuna, thawing overnight with sprays is generally employed, which in most cases is sufficient to thaw them. In some canneries, a cold-storage room is available for holding any surplus tuna. Such tuna can be withdrawn at a suitable time so as to be thawed when the canning operation starts.

Subsequent Processing Steps

The thawed or nearly thawed tuna pass along a motor-driven moving-slat butchering table, where they are eviscerated. At the same time, they are inspected to eliminate any that may be of doubtful quality. The butchered tuna are placed in baskets, which are arranged on racks. The tuna then are ready for the various canning operations. [The canning procedures for tuna have been described by Jarvis (1943) and by Anderson, Stolting, and Associates (1953).]

HANDLING OF SHELLFISH PRELIMINARY TO PROCESSING

The most important commercial species of shellfish in the United States are shrimp, crabs, lobsters, clams, oysters, and scallops. The methods of processing these shellfish are described in detail in section 2, Fishery Leaflet 430. Methods of unloading and of preliminary handling at the shore plant that are not discussed in the above leaflet will be described here.

Shrimp

In the South Atlantic and Gulf areas, the following three methods

are used to unload shrimp from boats to shore plants: (1) the basket method, (2) the modified conveyor method, and (3) the all-conveyor method.

The basket method is used to unload shrimp from boats into trucks for subsequent transportation to the shore plant. A wire basket that will hold about 100 pounds of whole shrimp is lowered into the hold of the boat by hand. The shrimp and ice (some "day-boats" do not use ice) are shoveled into the basket, which is lifted to the deck of the boat by hand. The shrimp then are dumped into the truck. After the boat is unloaded, the truck delivers the shrimp to the plant for processing.



Figure 38.—Hoisting baskets from the hold of a shrimp trawler.

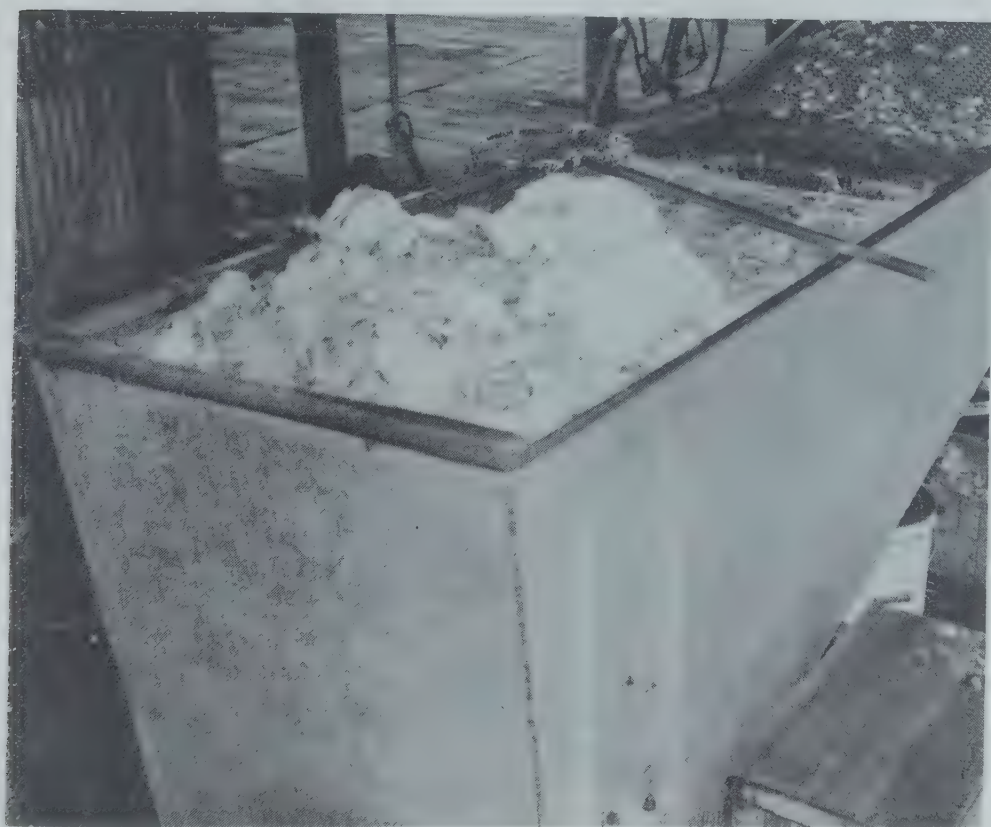


Figure 39.—Tank in which shrimp are de-iced and washed.

The modified conveyor method is used to unload shrimp at a dock adjacent to the processing plant. A wire basket is lowered by an electric winch into the hold of the fishing vessel. The shrimp and the accompanying ice are carefully shoveled into the basket, which then is hoisted to the wharf, where the contents of the basket are dumped into a de-icing and washing tank. This tank is a large rectangularly shaped metal container filled with a continuously changing supply of clean cold water. An inclined conveyor extends into the

tank and carries the de-iced and washed shrimp into the plant for processing (Strasburger 1954).

The all-conveyor method also is used to unload shrimp at docks adjacent to the shore plant. This method differs from the modified conveyor method in that a conveyor is used in place of a basket to lift the shrimp and ice from the hold of the vessel. The conveyor is lowered to the level of the hold, and the shrimp and ice are shoveled, by hand, onto the conveyor. The shrimp then are elevated to the de-icing and washing tank, and the procedure that was described previously is continued.

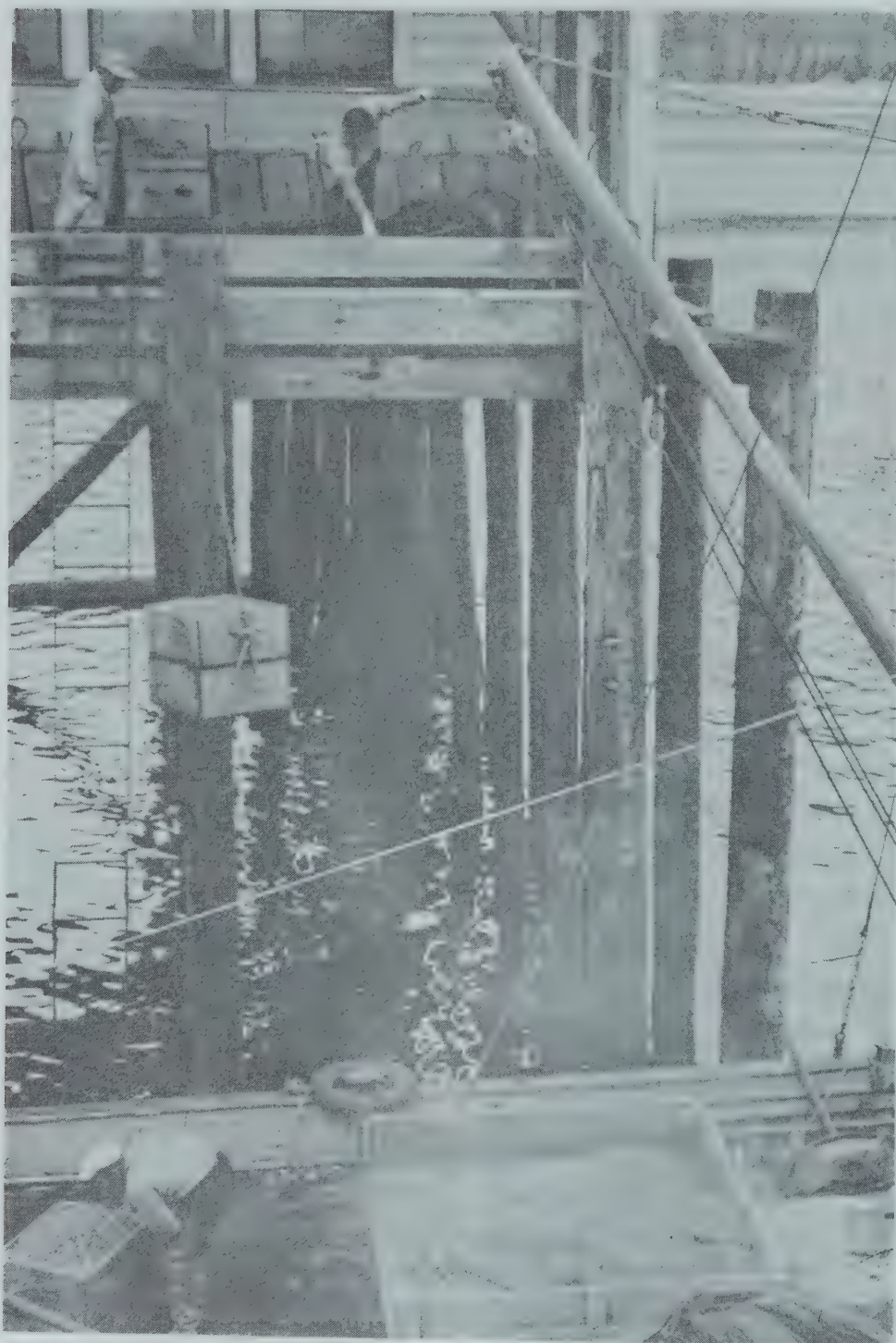


Figure 40.—Unloading boxes of whole shrimp.

In Alaska, the method of unloading shrimp is very simple. The shrimp, after being caught, may be placed in boxes, which hold 150 to 200 pounds, and are stored on the deck of the vessel. No ice is used because the air temperatures are low, and deliveries are made daily. At the shore plant, two or three boxes of shrimp are stacked, and two slings with hooks at the ends are threaded through rope handles on each box. The hooks are caught on the handles of the box at the bottom of the stack, and the boxes then are elevated to the dock with a boom-hoist. The boxes of shrimp are placed on a wheeled truck and are moved to the plant for processing.

Shrimp are processed as rapidly as is possible, in order to prevent spoilage. At times, however, it is necessary to store the shrimp for short periods.

As the shrimp are unloaded from the boats, they are de-iced and washed in tanks, inspected for spoilage, graded, and weighed. They then are re-iced and placed in cool rooms to await processing (Duggan 1954).

Lobsters and Crabs

Lobsters and crabs are delivered alive to the shore plant; dead lobsters and crabs are discarded. On the Atlantic coast, lobsters are covered with seaweed and are transported in wooden boxes aboard the vessel. After being landed at the processing plant, the lobsters are kept alive in sea water in specially constructed tanks until marketed. Crabs are marketed as delivered or are processed within a short time after being captured. On the Pacific coast, crabs are transported in sea water in live wells, aboard the larger vessels, or simply in boxes, aboard the smaller ones. After being landed, the crabs are held in boxes if they are to be processed within a few hours or, if they are to be held for a longer time, they are kept alive in holding pens through which sea water can circulate freely.

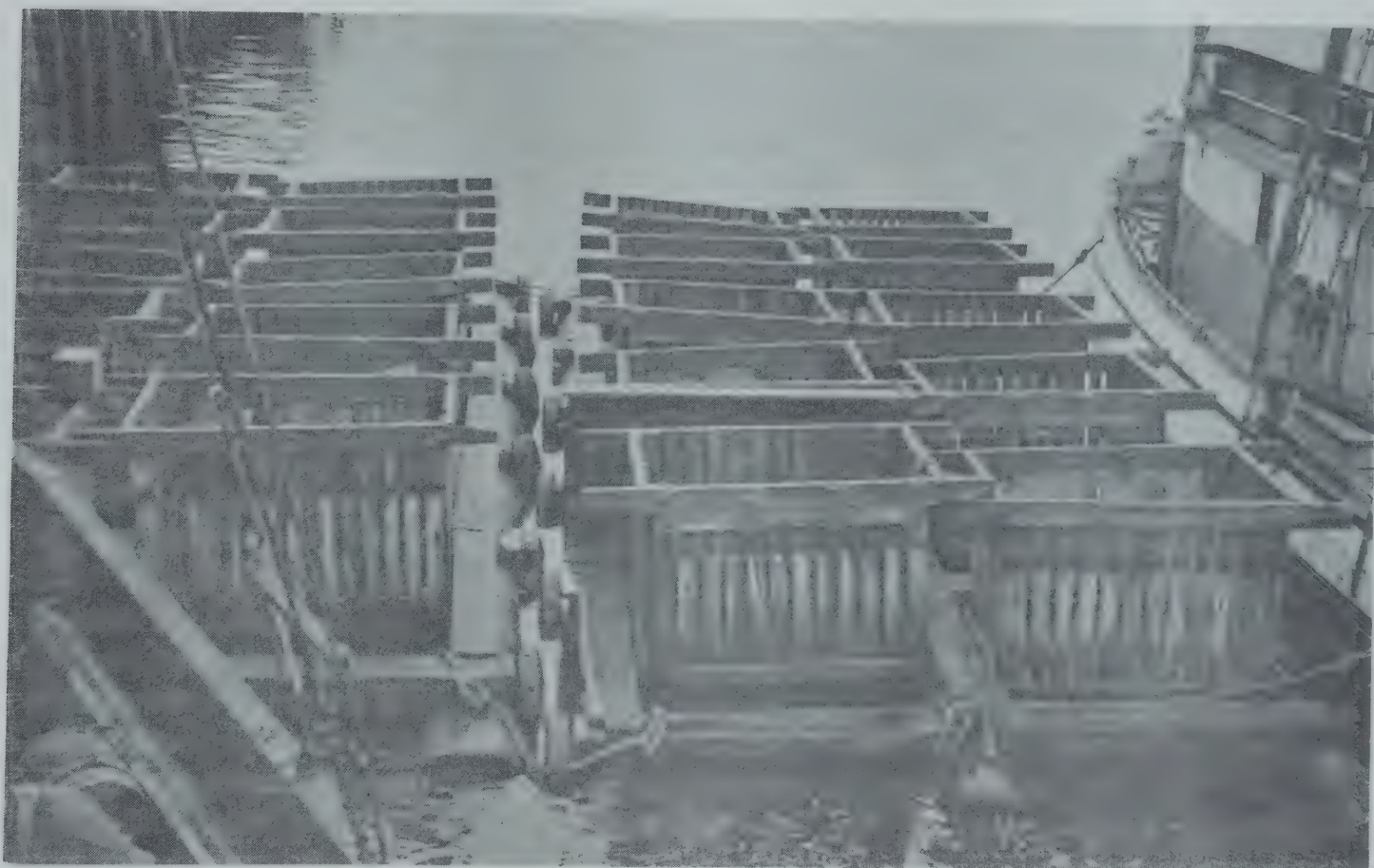


Figure 41.—Submersible live-boxes for holding Dungeness crabs.

Clams

All species of clams are delivered to the shore plant alive. They usually are delivered in sacks or in boxes, by boat or by truck depending

on where the clams were dug. No refrigeration, such as holding in ice, is used during transportation; however, the clams are kept cool and moist. On arrival at the cannery, they are inspected, and dead or broken clams are discarded. Prior to being processed, the clams are stored in areas where it is cool or are held in chill rooms.

Oysters

Oysters are delivered alive in the shell to the shore plant. They are unloaded from the boats by means of a bucket and hoist and, in the larger plants, by means of conveyors. In some plants, the oysters are conveyed directly to the tables for shucking; dead oysters are discarded. In others, the mud is washed from the oysters, and they are held for 24 hours in running sea water to which free chlorine gas is added in a concentration sufficient to sterilize the shells (Tressler and Lemon 1951). Oysters, while awaiting processing or marketing in the shell, are held in cool areas to preserve quality.

Scallops

Scallops are delivered to the shore plant nearly ready for marketing. The edible meat, which is the large muscle, is removed aboard the fishing vessel. The meats are washed carefully, put in 2-gallon cloth bags, and held in ice in the fish hold until landed (Anonymous 1952c). At the shore plant, the scallop meat is rewashed and is packed into 5- and 10-pound waxed cartons. The scallop meat then is kept at 35° to 40° F. until marketed, or it is frozen for storage or for distribution to inland markets.

RECOMMENDATIONS FOR THE CONTROL OF QUALITY AT THE SHORE PLANT

Fish—Before Processing

1. The pewing of fish should be discouraged. If pews must be used, only those with a single tine should be employed. Pewed fish should be pierced only in the head.

2. When fish are stored for future processing, the pile of fish should not exceed $2\frac{1}{2}$ feet in depth, in order to prevent crushing of the fish on the bottom of the pile. The use of shallow boxes or of bins helps to prevent crushing.

Flaked or finely crushed ice should be layered with the fish, and sufficient ice should be used to hold the fish at temperatures not higher than 35° F. Lump ice should not be used because it tends to bruise the flesh.

Adequate drainage is necessary to prevent blood and slime, washed down by the melting ice, from accumulating around the fish at the bottom of the pile.

3.—All equipment that comes into contact with the fish should be

thoroughly cleaned by the use of a stiff brush and of running chlorinated water. Steam, if available, should be employed. This cleaning should be done daily because scales and slime, when allowed to become dry, are very difficult to remove.

4. All equipment should be painted periodically in order to facilitate cleaning and maintenance and to help to eliminate bacterial contamination. For inside surfaces of weighing boxes, storage boxes, and hand carts, a bakelite varnish is recommended. Sheet-metal inserts for these containers are also recommended in order to eliminate the damage done to wooden surfaces by pews.

5. If boxes of fish are exposed to the sun, the fish should be well covered with ice, and the whole box should be covered with a tarpaulin.

Fish--During Processing

1. All equipment that comes into contact with the fish flesh should be thoroughly cleaned at the end of each day's operation in order to eliminate sources of bacterial and off-odor contamination.

2. Before the fish are cut, they should be thoroughly washed to remove blood and slime. Such washing will greatly reduce bacterial contamination of the fillets and processing equipment by removing the bacteria-laden slime.

3. Removing the nape, or the belly flap, from fillets will result in higher-quality fillets. It is in the nape that a fish will show the first signs of deterioration.

4. Fillets should be washed, preferably with chlorinated water, as is done in a brine dip. The washing will reduce the bacteria on the surface of the fillet and will extend the storage life of the flesh.

5. If possible, packaged fresh-fish products should be prechilled to a temperature at which the flesh will almost start to freeze (about 30° F.). This prechilling is very important for fish that is to be shipped long distances.

6. If the fish are to be held in storage before being shipped, the iced boxes of fish should be stored in a chill room at 31° to 32° F.

Shellfish

1. Federal, state, and territorial regulations should be followed regarding sanitation in the shellfish industry.

2. Shellfish should be kept cool and moist at all times (in ice, in cool rooms, or in live-boxes) while being held for processing or use in the fresh trade.

3. The handling of shellfish should be kept to a minimum, and care should be taken not to damage them by rough handling.

4. Dead shellfish such as crabs, lobsters, oysters, and clams should be discarded.

LITERATURE CITED

ANDERSON, A. W.; STOLTING, W. H.; and ASSOCIATES

1953. Survey of the domestic tuna industry. Special Scientific Report: Fisheries No. 104, United States Department of the Interior, Fish and Wildlife Service, Washington, D. C.

ANONYMOUS

1946. Manual of recommended practice for sanitary control of the shellfish industry. U. S. Public Health Service, Public Health Bulletin No. 295.

ANONYMOUS

- 1947a. Proper fish plant sanitation. Fishing Gazette, vol. 64, No. 13, December, p. 46.

ANONYMOUS

- 1947b. The use of chlorine disinfectants in fish plants. Fisheries Research Board of Canada, Progress Report of the Atlantic Coast Stations, No. 40, November, pp. 9-11.

ANONYMOUS

1951. Longer-life cutting table. Food Engineering, vol. 23, No. 8, August, p. 11.

ANONYMOUS

- 1952a. Extermination of rodents. Food Manufacture, vol. 27, No. 9, September, p. 374.

ANONYMOUS

- 1952b. Insecticide incorporated in paint retains effectiveness for life of paint. Food Processing, vol. 13, No. 2, February, p. 73.

ANONYMOUS

- 1952c. Modern scallop production. Fishing Gazette, vol. 69, No. 8, August, p. 31.

ANONYMOUS

1954. British develop novel method of determining freshness of fish.
U. S. Department of Interior, Fish and Wildlife Service
Fishery Products Report No. S-42, March.

BEARD, HARRY R.

1953. NEFCO from sea to world markets. New England Fish Company
25th Anniversary Edition, p. 96.

DUGGAN, J. ROY

1954. Handling shrimp in the breeding plant. Southern Fisherman
Yearbook, March, pp. 62-64.

HOLSTON, J., and POTTINGER, S. R.

1955. Brine dipping of haddock fillets. Commercial Fisheries
Review, vol. 17, No. 10, October, pp. 21-30.

HURLEY, STANLEY P.

1949. Sanitation problems in the fishing industry. Food Technology,
vol. III, No. 12, December, pp. 416-418.

JARVIS, NORMAN D.

1943. Principles and methods in the canning of fishery products.
Research Report No. 7, United States Department of the
Interior, Fish and Wildlife Service, Washington, D. C.

KAYLOR, JOHN D.

1950. Plant sanitation. Techno-Logic, vol. 2, No. 2, Technological
Section, National Fisheries Institute, Washington, D. C.,
February, pp. 1-4.

MAGNUSSON, HARRIS W., and HARTSHORNE, J. C.

1952. Freezing fish at sea--New England. Part 5 - Freezing and
thawing studies and suggestions for commercial equipment.
Commercial Fisheries Review, vol. 14, No. 12a, December,
pp. 8-23.

SALTON, M. R. J.

1948. The use of surface active cations in detergency and sterilization. Food Preservation Quarterly, vol. 8, No. 1, March, pp. 10-15.

SOMERS, IRA I.

1949. How to select detergents for food plant cleaning. Food Industries, vol. 21, No. 3, March, p. 72.

STRASBURGER, L. W.

1954. Handling shrimp in the packing and freezing plant. Southern Fisherman Yearbook, March, pp. 58-61.

TRESSLER, DONALD K., and LEMON, JAMES McW.

1951. Marine Products of Commerce. Reinhold Publishing Corp., New York 18, New York, second edition.

WAIDELICH, A. T.

1951. Designing sanitation into food plants. Food Technology, vol. 5, No. 6, June, pp. 244-246.

Reprinted 1963

C. F. T. R. I.
FOOD TECHNOLOGY EXPERIMENT STATION
Bangalore, MANGALORE-1.



As the Nation's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States—now and in the future.

C. F. T. R. I.
FISH TECHNOLOGY EXPERIMENT STATION,
MADRAS BRANCH, MANGALORE-1.



